13. CONTAMINANTS STANDARDS

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13. CONTAMINANTS

The evaluation of the contaminant hazard in space operations is a difficult problem that has as yet not been adequately solved. The variables and unknowns are numerous (94, 203). Data to be presented below will be restricted to those empirically derived. An attempt will be made to present those theoretical considerations which must be understood in order to extrapolate the data to space cabin conditions. In view of the current uncertainties regarding the data, no recommendations will be made on limits for continuous exposure to toxic trace contaminants other than those suggested by the NAS-NRC (136).

GENERAL EVALUATION OF THE CONTAMINANT PROBLEM

Toxicological problems in space operations cover three situations: (1) the acute, short term, high-level exposure either in ground support or space cabin conditions; (2) the 8-hour work day exposure found in manufacturing and ground support situations; and (3) continuous, long term exposure to trace contaminants, such as would be anticipated in extended space missions.

A completely new and unique aspect of toxicology has evolved from the aerospace mission, for which no parallel exists in previous experience in industrial hygiene or occupational medicine. This situation exists for two reasons: the increased use of multi-ton quantities of high energy, physiologically-reactive compounds with the inherent increased possibility of accidental exposure; and the contemplated long-term space mission within a closed system, in which, unlike submarine conditions, unlimited power is not available for complete control of the environmental atmosphere. The greatest need for toxicological information in both situations is for inhalation data. Up to the present, the only guidelines available to the toxicologist are the Threshold Limit Values (TLV) established by the American Conference on Governmental and Industrial Hygienists (6, 199), the maximal allowable concentrations of the American Standards Association's Z-37 Committee (210), and the more recent recommendations made by the ad hoc committee on Air Standards of the Committee on Life Sciences, National Academy of Sciences (136). These values represent, for the most part, time-weighted average concentrations to which nearly all workers can be exposed 8 hours daily, 5 days per week throughout their working lifetime without adverse effects on health. The last of these guidelines extends few TLV data to space conditions.

Safe exposure levels to air pollutants in community, industrial and military situations are based mainly on industrial experiences, animal studies, human volunteer exposures or a combination of the three. Because it is rare that industrial experience can supply both environmental and medical data adequately controlled in respect to exposure conditions, data from animal studies are more commonly used where such controls can be maintained and the progress of the response determined at will. Increasing use of data from human volunteer exposures is being made to provide the desired correlations

between animal and human experiences. Data from whatever source is then evaluated by a committee of individuals of long and continuing experience in industrial health for what limit in their judgment is appropriate. The continual surveillance on the suitability of the industrial air limits, which now number more than 400 and a substantial number (67%) of which have been satisfactorily used without change for from 20 to 25 years, offer mute testimony to their validity. In this connection, it is interesting to note that experience has been equally good with industrial air limits based on animal studies as those based on human experience and industrial surveys (65%). (198) Each limit is documented by pertinent literature references with a clear statement on the nature of the response against which the limit protects.

It should be most emphatically noted that in our present state of knowledge none of the industrial air limits can be used with certainty either directly or by extrapolation for space cabin environments. Although such an extrapolating equation has been proposed (200) in which all variables likely to affect toxicity were included, subsequent experimental animal work (205) showed that such a procedure could not be relied on in any given case; in our present state of knowledge, the rate of metabolism varied unpredictably from one pollutant to another under conditions of continuous exposure relative to intermittent exposure. This parameter appeared to be overriding, at least as far as animal studies indicated, but it should be noted that animal studies are incapable of revealing the magnitude of several of the factors included in the extrapolation equation. How unpredictable is the application of the TLVs of industry to space cabin conditions is shown in the above-mentioned studies (205). The intermittent, 8-hour industrial TLV for phenol appeared to be a satisfactory TLV for the 90-day continuous TLV for space; possibly also for carbon tetrachloride, but not for hydrazine, unsym. dimethyl hydrazine, nitrogen dioxide, decaborane, hydrogen sulfide or methyl mercaptan.

The industrial air limits would appear to be also inadequate for extrapolation to the space cabin environment in terms of other critical factors of the environment such as pressure, atmosphere, relative humidity, radiation, thermal, and other factors. Even the 90-day exposure limits set for submarines are not directly applicable because of these variables (27, 151, 200). Efforts to use these values when mixtures of toxic materials are involved, as is almost always the case in aerospace situations, are not only meaningless but dangerous.

In view of the necessity for provisional limits of manned space flights of 90- to 1000-days' duration, the NAS-NRC committee has derived the following criteria for trace contaminant control in manned spacecraft (136):

1) Contaminants must not produce significant adverse changes in the physiological, biochemical, or mental stability of the crew.

2) The spacecraft environment must not contribute to a performance decrement of the crew that will endanger mission objectives.

3) The spacecraft environment must not interfere with physical or biological experiments nor with medical monitoring.

For the purposes of these provisional criteria, the Committee assumes a spacecraft atmosphere ranging from 760 to 258 mm Hg total pressure, containing nitrogen as a diluent gas, oxygen sufficient to maintain normal (sea-level equivalent) alveolar partial pressure, and carbon dioxide below 5 mm Hg. Temperature and relative humidity are within the comfort zone for the total pressure selected.

This rigorous approach is also consistent with scientific requirements. The NASA Space Medicine Advisory Group and the Respiratory Physiology Group of the Space Science Board's 1966 Summer Study have reaffirmed the principle that engineering exigencies should not dictate the environment: the environment must be supplied to provide the best medium for the experimental effort and one might also add, the best medium for the mission profile. Thus, if one of the goals of prolonged manned spaceflight is to ascertain man's adaptability and response to the weightless environment, it is necessary to design manned spacecraft in such a fashion that the Earth atmosphere or a reasonable facsimile thereof be provided in order not to prejudice the study of the one facet of spaceflight that cannot be duplicated on Earth - weightlessness.

The NAS-NRC has therefore developed conservative air quality standards for prolonged manned missions on the following premises: (136)

1) Any contamination of the spacecraft atmosphere may be detrimental.

2) Zero contamination level of the spacecraft atmosphere is impossible.

3) Data do not exist that will permit one to predict with certainty the maximum contaminant concentration that will not cause degradation of the mission.

4) Provisional limit values can be established for some contaminants to serve as guidelines in design, development, and testing of future space systems.

5) These provisional limit values can, perhaps, ultimately be transformed into limit values if sufficient data about the effects of continuous exposure to a single compound and to multiple compounds can be obtained.

The uncertainties in establishing even provisional limits for prolonged manned missions are many and range from engineering, to environmental, to toxicological considerations. Since the materials to be used in future spacecraft construction and the type of regenerative environmental control system(s) to be employed have not been determined, there are major uncertainties regarding the kind and amount of air contaminants that will be present. There is also a major uncertainty as to how reduced pressure may alter the toxicity of contaminants.

A further consideration is the fact that most of the available data have been obtained on subjects in a "normal" physiological state. The effect of stress, prolonged confinement, weightlessness, and other factors that might

tend to alter man's normal physiology, and thus change his response to any given compound cannot be accurately predicted at this time. For all these reasons, the limits recommended by the NAS-NRC Committee are provisional, and subject to revision. (See discussion of Table 13-15 on page 13-56.)

Programs have been established to provide specific toxicological information on selected propellants and to study the effects of long term, continuous exposure to possible trace contaminants at reduced atmospheric pressures and under the influence of one- and two-gas systems (oxygen or oxygen/nitrogen) (2, 136, 203). These programs include definitive measurements of physiological changes as evidenced by clinical chemistry, changes in behavioral patterns, and gross and microscopic pathology. It is hoped these will allow a more definitive evaluation of the space cabin problem.

KINETICS OF CONTAMINANTS IN SPACE CABINS

Units

There are several ways of expressing exposure or dose. One procedure describes the quantity in terms of a weight or volume of material per unit weight of the animal, for example, mg/kg. When speaking of the concentrations of a gas or particulate in the air, the term parts per million (ppm) or mg/cu M are generally employed. The former is a v/v relationship. In air exposures the time of contact in minutes or hours is included. In the space cabin environment with an altered partial pressure of the atmosphere, it has been suggested that micromoles/cu M or millimoles/25M^3 may be a more reasonable way to express the data (136). The latter unit gives a numerical value which,at 1 atmosphere pressure and at 25°C,is the equivalent of ppm by volume (the units used for submarine standards and by the American Conference of Government Industrial Hygienists). At the same time it expresses the molar concentration per unit of space volume and is, therefore, equivalent to partial pressure of the contaminant. Unfortunately, the toxicological literature makes little or no use of these expressions as standard terms.

The percent of animals affected is defined as a subscript 0, 50, or 100, etc. Since lethality is often the outcome, a lethal dose is abbreviated as LD and the lethal concentration as LC. When subscripts are not used, the value has probably been based on limited observations and hence lack statistical validity. The concept of threshold limit value (TLV) and maximum allowable concentration (MAC) has been discussed above.

Buildup of Contaminants

The primary and secondary factors controlling the buildup of contaminants in sealed cabins are seen in Table 13-1. Asterisks indicate those factors not present or significantly different in submarines.

Table 13-1

Important Factors Influencing Atmospheric Contaminations in Sealed Cabins

(After Thomas [203])

Aggravating	Beneficial
Continuous Generation and Exposure	Leak Rate of Cabin
* Reduced Pressure	Materials Selection
* Volume/Man Ratio	Preconditioning of Materials
* Power and Weight Limitation	
Filter Characteristics	
Complexity of Contaminants	
* Multi-Stress of Environment	
* Escape Lead Time	

* Not significant in nuclear submarines.

For a given compound or element, the concentration of its vapors within a closed space is determined by the difference in the rate at which the vapor is generated, and the rate at which the vapor is removed from the atmosphere of the closed space:

$$\frac{d}{dt} C = \frac{d}{dt} G - \frac{d}{dt} A, \qquad (1)$$

where C = rate of contaminant buildup;

G = rate of contaminant evolved;

A = rate of contaminant removed.

G is a function of the Molecular Weight of the compound or element, of the surface area exposed to the specific cabin atmosphere, and of its temperature in usage. These parameters determine the "contaminating efficiency." A is the "decontaminating efficiency" of the Environmental Control System, and is usually designed on principles of chemical removal, or of physical removal, or of a combination of both (ex: chemisorption, or reaction; cryogenic condensation, or physical adsorption). By these means, the contaminant is brought into a solid or liquid phase having a considerably lower vapor pressure than the original.

The surface area of the material exposed to the cabin atmosphere must be known, or closely estimated. The vapor pressure of the contaminating material and its usage temperature, as well as its molecular weight must be known, or calculated from Equation (2):

$$\mathrm{Log}_{10} p = - \frac{0.0523}{T} A + E, \qquad (2)$$

where p = pressure in mm Hg of the saturated vapor pressure at temperature T;

T = temperature of material, degrees K;

A, E = constants, the values of which are reported in the literature for a vast number of chemical elements and compounds (51, 88, 93, 129. 157, 193).

The weight rate at which contaminating vapor is generated as a function of its molecular weight and temperature must be known, or calculated by the Langmuir equation:

$$G = \frac{p}{17.4} \cdot \left(\frac{T}{M}\right)^{\frac{1}{2}} \qquad (3)$$

where G = weight rate of vapor generated, in gms, per unit area of contaminating material;

p = pressure in mm Hg of the saturated vapor pressure at temperature T;

T = temperature of material, degrees K;

M = molecular (atomic) weight of material.

For toxicity evaluation purposes, the above information is useful when rendered in units of parts per million by volume. Therefore, the free volume, V_f, of the closed cabin must be known, or closely estimated, and the cabin pressure, P_C, must also be known. Hence, integration of Equation (1) over the time considered yields the mass (in grams) of contaminant in the closed cabin atmosphere, per unit area of material.

Equation (3) may be more useful and more easily handled, as the weight of contaminant is determined directly by multiplying the value of G by the time and the surface area (time interval over which the calculation is made, e.g., mission time; and surface area of material exposed to cabin atmosphere):

$$G \text{ in } \frac{\text{gms}}{\text{Cm}^2 \cdot \text{Sec}} \cdot \text{Cm}^2 \cdot \text{Sec} = G' \text{gms} \qquad (4)$$

Then:

$$V_a = \frac{G'}{M}\left(22,\ 415\right) \qquad (5)$$

where V_a = volume of the G'weight of contaminant, atmospheric pressure, cubic centimeters;

M = molecular (atomic) weight of contaminant grams;

22, 415 = volume of 1 mole contaminant at 760 mm Hg pressure, in cubic centimeters:

And then, correcting for cabin pressure,

$$V_c = V_a \cdot \frac{760}{P_c} \qquad (6)$$

where V_c = volume of the G' weight of contaminant, at cabin pressure, cubic centimeters;

P_c = pressure of cabin atmosphere, mm Hg.

This volume, V_c, may now be expressed in parts per million of free cabin atmosphere:

$$ppm = \frac{V_c}{V_f} \cdot \frac{F}{F} \tag{7}$$

where V_c = volume, in cm cubic, as defined above;

V_f = free volume of closed cabin, in cc.;

F = of a value such that when multiplied by V_f yields a product of 1 million.

Ideally, the above considerations could provide the basis for controlling the undesirable constituents of space cabin atmospheres providing that in each case an appropriate exposure value could be stated. Were it possible to do this and if the expressions above could be organized into a set of nomograms, a desirable way to present the information would be to develop a final nomogram combining Equations (5), (6), and (7) with a scale of limiting values for concentration and duration of exposure. Sets of such nomograms might be developed each for a different class of contaminant. This ideal cannot yet be achieved.

The concentration of a contaminant in a cabin at time t after closure can be determined by the equation:

$$C = \frac{W}{b} (1 - e^{\frac{-(bt)}{a}} \tag{8}$$

where C = mg/m^3 of contaminant at time t;

W = mg contaminant generated per day;

a = m^3 total effective gaseous volume;

b = m^3 atmosphere leaked per day at x psia;

t = days elapsed time;

e = 2.718.

This equation suggests that an equilibrium level of contaminant will be reached. The time to reach 99% of equilibrium concentration after closure can be estimated by the equation:

$$t_{days} = 4.6 \frac{a}{b} \tag{9}$$

where a = m^3 total effective volume

b = m^3 leak per day at x psia.

The concentration at equilibrium and the time to reach this concentration (Equation 9) are determined by the variables of Equation (8). This is a key factor in establishing the relative rate of chemical removal and purge or venting removal needed to attain a given equilibrium level in the atmosphere.

To summarize the salient features of the contaminant build-up hazards, the following axioms can be stated: (204)

- Given a certain cabin volume, the time of equilibration of contaminant concentrations in the atmosphere is independent of the final concentration attained, if contaminant generation and removal rates are held constant. Under certain conditions, the virtual (but not the true) rates of contaminant generation can become constant since the decreasing rate of gas-off from materials is balanced out by the progressive loss of filtering efficiency.
- The magnitude of the final equilibrium concentration of contaminants is directly proportional to the generation rate and inversely proportional to the removal rate in sealed cabins.
- Contaminant concentration rises rapidly at first and then approaches a constant value (equilibrium concentration) at infinite time.

From a practical standpoint, the design engineer has primarily to worry about contaminant removal rates to keep the atmosphere habitable on long duration missions. Removal rates depend on what contaminants are lost together with the cabin atmosphere as the result of outboard leak and the amount of contaminants that are adsorbed on the various filter beds. Leak rates are the most effective disposal methods for contaminants. They also have the greatest impact on the rate at which contaminants accumulate in the cabin (230). Since large leak rates are undesirable from a logistics standpoint, other means of contaminant elimination must be found. To simplify calculations, "equivalent leak-rate times" can be used for rating filters, scrubbers or other air purification equipment. This "equivalent leak-rate time" (ELRT) can be defined as the volume of atmosphere that has been "absolutely cleaned of contaminants" in one day's time, with specific consideration for the efficiency of the purification unit. For example: A filter operating at 50% efficiency would remove only 1/2 of the contaminants present in a unit-volume of air passing through it. On the second passage through, it would remove 1/2 of the remainder, etc.

In evaluating the buildup rate, important secondary factors to be considered for each contaminant are the kinetics of adsorption along adsorption beds and the break-through curves for the gas-bed system (33, 157). The problem with filters is that their efficiency decreases with time as the filter bed saturates with contaminants and as the flow rates through the filter drop due to particles obliterating the free passage of atmosphere. Typical curves are seen in Figure 13-2. These curves also determine the nature and timing of secondary chemical reactions which can occur on the bed and thus the alteration in the nature of the trace contaminants to be considered. It can be seen that with increasing time, filter efficiency decreases in an exponential fashion that is quite similar to the build-up of contaminants. Consequently, the inefficiencies of filters on long-duration missions will be greatly aggravated by the contaminant build-up if there is no substantial outboard leak or controlled dumping. Moreover, nuclear submarine experience indicates that adsorbent beds become saturated with high boiling hydrocarbons within two to three days and permit the low boiling point materials to pass through,

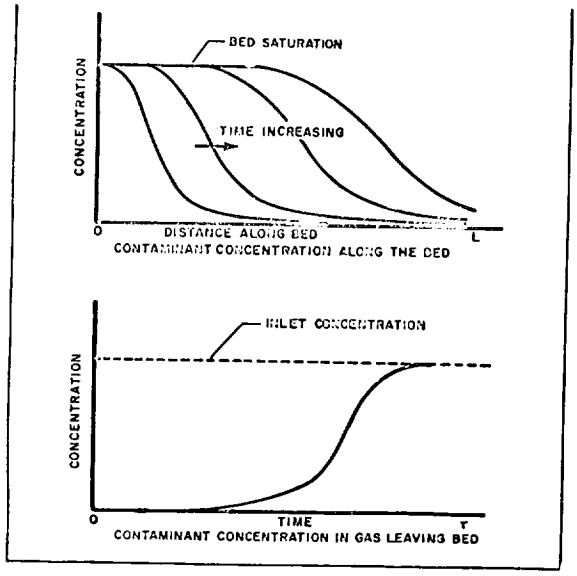


Figure 13-2

Concentration Profiles in Sorption Beds

(After Thomas [203])

even displacing these. Until specific adsorption coefficients become available for particular materials and periods of time, generous safety factors should be used in calculating the amount of adsorbents. Preliminary design data are available on isotope-heated, catalytic oxidizing systems for contaminant removal in future space vehicles (142).

Generation of contaminants can be controlled by appropriate care in the design and manufacture of space cabins. A handbook is available covering recommendations for contaminant control in the Apollo Program (138). The Soviet approach to the kinetics of contaminant control has been recorded (24).

TOXICOLOGICAL FACTORS

All compounds capable of chemical reaction have an adverse effect on the body at some quantity or concentration (50, 52, 145, 177, 218). Toxicity is inherent in all substances; the question, therefore, is: what is the intensity and duration of the exposure? By the process of homeostasis through alteration of physiological and biochemical mechanisms, the body is capable of maintaining its normal healthy internal environment up to a point. If that point is exceeded, then adverse effects may occur. Exposure to chemical substances may be single, repeated, or continuous. The vast majority of toxicologic research has been based on the first two of these relationships. As a rule, a single exposure, if it does not result in death, does not produce persistent deleterious effects in biochemistry, physiology, or structure; but this may not be so in the case of carcinogens. Recovery occurs rapidly. However, in the case of substances taken into the body repeatedly or continuously, while not producing immediate change, may slowly exert a deleterious effect. This occurs in one of two ways. Either the substance may collect in the body to such an extent that eventually the concentration is great enough to cause change; or repeated small injuries may summate to the point where normal biochemical, physiological, or tissue-restorative abilities are exhausted. Agents like carcinogens or beryllium may have complex dose-intermediate-response relationships.

Classification of Toxic Agents

Toxicological agents may be classified in many ways. The following is one of the simplest breakdowns relative to the space problem.

1) Asphyxiant. Any agent which interferes with the oxygen supply or its utilization. In the narrower definition of this term, the presence of increased carbon dioxide in blood or tissues is added.
   a) Simple asphyxiant. These act by physical displacement of the oxygen available in the atmosphere and, thereby, reduce the concentration of oxygen in the lungs. This type of agent is effective only at relatively high concentrations and, therefore, can be detected easily. For this reason, it is not likely to be important as a trace contaminant.
   b) Biochemical asphyxiants. These act by blocking any step along the path of oxygen transport or utilization. Since most of these agents are very active biochemically, they may be effective in very small concentrations. Any agent blocking the respiratory center will cause hypoxia and CO_2 retention. As another example, carbon monoxide has a much greater ability to bind hemoglobin than does oxygen. Thus, trace levels of carbon monoxide can result in a significant decrease of oxygen available to the tissues. At the cellular level, the cyanide group binds oxidative enzymes and, thereby, prevents the uptake and utilization of oxygen available in the blood. Regardless of the level of the block in oxygen transport or utilization, however, asphyxia results in degraded tissue function and, if sustained, may result in irreversible tissue damage. The higher centers of the central nervous system are especially sensitive to this hypoxic effect.

2) Irritant. Any agent which produces an undesirable response of a tissue, but not necessarily one which results in tissue destruction. Both the response and tissue damage may vary with concentration. Internal organs may be irritated, but often the symptoms are not as specific as in external irritations.
   a) The effect may be one of local stimulation of function, local depression of normal function, local inflammation, or local sensory reaction.
   b) The tissues most frequently involved are the skin, mucous membranes, cornea, and the gastro-intestinal tract.

   The primary effects may include itching, burning sensations of the eyes and/or respiratory tract, or skin or other local inflammation. Each of these effects may be accompanied by pain, annoyance, distraction, or a major psychological reaction or disruption. In addition, physiological stress reactions may be a secondary effect. Corneal irritation causes tearing and, consequently, a loss of visual functions and sensitivities. Severe respiratory irritation can result in pulmonary edema and a consequent asphyxiation. Reactions to skin irritations such as scratching and ulceration provide possibilities for infection and for the spread of the agent.

3) Toxicant. Any agent which produces either temporary or permanent interference with normal function. Toxicants which produce the most rapid effect and the greatest threat to survival of space crews are those which affect the central nervous system including consciousness. Asphyxiants, narcotics, and psychochemicals are of this sort. Manifest toxicity to other tissues may be less rapid, but eventually as damaging as that to the central nervous system, e.g., bone marrow damage, hepatic or renal dysfunction, etc. The most important effect is on the central nervous system. A critical criterion is loss of consciousness or a reduced level of alert functioning both of which may be a serious hazard. Toxicity to other organs may be less of a mission hazard; that is, it may permit completion of a mission, but then be followed by severe, though delayed, effects (e.g., on bone marrow, kidneys, etc.).

Processing of Toxic Agents by the Body

The time during which chemicals remain within the body depends on factors of absorption, elimination, storage, and biotransformation. The quantity of a chemical not essential to the normal functioning of the body but present in the tissues, is termed "the body burden". It is generally expressed in weight of substance (ug or mg) per unit weight (kg or per 100 grams) of tissue.

Absorption

Chemicals of immediate concern in space cabins enter the body principally through inhalation and skin absorption; oral ingestion is not as important. With inhalation, absorption is rapid and maximum blood levels are usually reached quickly. (Carbon monoxide is a classical exception.) Total quantity absorbed by this route is influenced by the rate and volume of respiration, the concentration of the contaminant, and the percentage extracted from the air. Experience has indicated the following contaminants have fairly easy access to the cell interior once they are absorbed into the body: gases, fat soluble compounds, organic bases, un-ionized combinations of weak acids. The following contaminants penetrate the cell membrane poorly; compounds with high water solubility, salts of organic basis, highly ionized compounds.

Storage

Chemicals entering through the lung are absorbed into the blood and distributed widely throughout the body. The site of maximum concentration generally depends on physical solubility and chemical reactivity of the absorbed substance. A great variety of chemical substances are stored in the body in trace amounts, frequently at levels which do not produce any known adverse effect. Metals that are bone-seekers remain in the body for years; chemicals that are non-reactive and fat soluble remain for months; however, the majority of substances are metabolized or excreted within hours or days.

Elimination

The principal routes of excretion are the expired air, urine, and feces. Less important, but not to be ignored, are the sloughed skin and perspiration. The more rapid the excretion, the less likely are toxic effects to occur.

Biotransformation

The majority of organic chemical substances are transformed by processes of oxidation, reduction, hydrolysis, and conjugation. These processes are termed biotransformations (230). The transformed substance may be more or less toxic than the original absorbed substance. There are frequently species, sex and age differences in the reactions, which make the extrapolation of animal data to man difficult.

Dose-Response Relationship

Quantitative relationship of dose and response are exceedingly important in the theoretical and practical evaluations of toxic action. In general, the greater the dose, the more severe the response or the more rapid is its onset. Time is an equally important factor in determining effect. In general, there are four possible relationships which can be expressed: (86)

- $E \sim C$; that is, the effect (E) is entirely due to the concentration (C). This condition probably never does exist in real situations where time, however short, is always involved.
- $E \sim Ct$, that is, the effect is the product of the concentration and the time (t) within certain limits. This relationship has been expressed as Haber's law:

$$C \times t^{(n)} = k \qquad (10)$$

  where n is an exponent which may itself change with time. This fact is most unfortunate in the complications which it presents in evaluating long missions with continually changing concentrations.

- $E \sim \frac{dC}{dT}$, that is, the effect is dependent on the rate at which the ingredient enters or leaves the cell.
- $E \sim (C-A)T$. In this equation the concentration in the body is corrected for the rate of biotransformation to more or less active substances (A).

Toxicity of Mixtures

Rarely are chemical toxicants present alone. In the problem of the space capsule, many hundreds may be present. The difficulty in evaluating the milieu of contaminants is the interaction which occurs due to the combined effect of these substances (170). In order to predict whether there is enhanced

or decreased effect, attention must be paid to the well-established phenomena of the combined effects of toxic substances which are:

Addition

An additive effect occurs when the fractions of the independently active components are equal to the effective dose of either alone. This can be expressed by the relationship for the TLV for additive components:

$$\frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \frac{C_3}{TLV_3} + \cdots\cdots \frac{C_n}{TLV_n} = 1.0 \qquad (11)$$

Potentiation

Potentiation is the enhanced effect from a combination of 2 or more substances, one of which shows no appreciable effects noted in the potentiation at any concentration. This may come about by the first sensitizing the point of action of the second substance or by decreasing the rate of its metabolic transformation.

Antagonism

Antagonism comes about by the nullification of the effect of one substance by another. There are generally three types: physiological, chemical, and competitive. Physiologic antagonism occurs when the chemicals act at different sites and produce opposite effects. Chemical antagonism results from the combination of one or more chemicals to yield an inactive form. Competitive antagonism implies competition for a single site of action for which both chemicals have an affinity.

Synergism

The joint action of two agents to give a combined effect greater than the algebraic sum of their individual effects is termed synergism. An equation similar to Equation (11) with a constant of <1 for synergism and >1 for antagonism may be used when the appropriate data are available.

Toxic Factors

In addition to the usual effects which may be predicted in the average individual, based on the observation of physiological, biochemical, and pathological changes which occur when sufficient doses of a toxicant are encountered, there are also unusual responses. These are unusual in that they occur generally at much lower doses than might be expected, require previous contact with the substance, or result in changes which are different from those normally expected.

Sensitization

This response, greater in magnitude than would be expected from known reactions to predicted doses, requires previous contact in order for it to occur. The theory is that an altered protein is formed by contact with an active chemical group. Subsequent contact with the offending agent will cause a release of antibodies which will result in local tissue changes of a shock-like nature. These may occur in the skin, respiratory tract, bone marrow, blood vessels, or general tissue structure.

Tolerance

With many chemicals, continuous or repeated exposure results in a progressive decrease in responsiveness and the dose necessary to elicit the response becomes greater. Mechanisms are related to an alteration in biotransformation and progressive desensitization of the responding organ.

Idiosyncratic Response

Adverse responses to extremely low doses of a chemical agent with manifestations of toxicity expected only at larger doses are termed idiosyncratic responses. The reason for this unusual susceptibility to the substance is not known. One cause is the lack, on a genetic basis, of particular detoxifying enzymes (196); another cause is the presence of increased end organ sensitivity for any one of several reasons.

Carcinogenesis

The development of neoplastic or cancerous tissue subsequent to the application of chemical agent is known as chemical carcinogenesis. Unlike other manifestations of toxicity which are universal from species to species and occur relatively close in point of time to exposure, carcinogens often show marked strain-specific sensitivity, have a prolonged latent period, and are not consistently related to dose.

Secondary Factors Modifying Toxic Action

A number of factors related to the external environment or the peculiarities of the test species modify the extent and threshold for toxic action.

Intrinsic Factors

The greatest single intrinsic factor influencing the response to a toxicant is the differences among species, although a ten-fold difference will often bracket the dose response for most species and man. Differences within the species may also account for ten-fold differences. Age modifies response, with great resistance occurring in the young adult and the greatest susceptibility found in the very young and very old. General physical condition and state of health determine responses, an adverse effect being seen in the less healthy state. Nutrition plays an important role and specific dietary deficiencies

may modify susceptibility. Tolerance developed to a particular agent may bring about resistance to progressively larger amounts of the agent.

Extrinsic Factors

The number and spacing of the doses, time of exposure, particle size and surface area of particulates, together with the total quantity administered, are the most important factors. The route of administration sometimes alters the response, as does the physical state of the substance and its degree of chemical reactivity as determined by solubility. Environment conditions such as state of nutrition temperature, pressure, and the presence of other chemical substances are important modifying factors, especially in the space cabin environment.

TOXICOLOGY IN THE SPACECRAFT ENVIRONMENT

In the context of cabin exposure, one is dealing with a toxicological problem involving the prediction of probable responses to a low level, continuous exposure to a mixture of chemicals, some of which are not as yet known. There is a constantly changing environment with each compound building up to equilibrium levels in variable periods of time. Programmed or accidental cabin depressurizations can cause sudden purges and reduction of concentration level to zero allowing excretion of the compound; then follows rebuildup in the body to a new equilibrium. There is simultaneous adaptation or desensitization and variable levels of cross tolerance between compounds (170). Cumulative effects under such a variable exposure background are most difficult to assess.

In order to set exposure limits in space operations, one must convert the usual industrial TLV values (TLV_{ind}) for 8 hrs/day, 5 days per week exposure to TLV values for continuous exposure in space (TLV_{space}). Experience with submarines has required extrapolation of industrial TLV data to 90 days continuous exposure (27, 151, 155, 187). At the industrial threshold limit and under normal conditions, continuous toxicity tests on animals for 90 days have shown evidence of a wide variation in safety factors of present threshold limits. These tests showed effects ranging from no mortality or other untoward effects, to moderate toxicity, to almost complete lethality in animals tested over 90 days at the threshold limit. It should be noted that taking animal responses to continuous exposure as a measure of the safety factor magnitude for intermittent exposure may not be entirely correct in all instances; all substances are not cumulative either in amount or in effect on continuous exposure. The technique does provide a rough estimate of the safety factor.

The following equation has been proposed: (200)

$$TLV_{space} = \frac{TLV_{ind} \times F_{press}}{F_{cont} \times F_{temp} \times F_{rm} \times F_{O_2} \times F_{fat} \times F^{*}_{int}} \qquad (12)$$

where F_{press} = Dosage factor from ambient pressure change to 5 psi = 3

F_{cont} = Toxicity factor from continuous dosage = 1 to 4

F_{temp} = Toxicity factor from temperature change, $F_{\Delta T}$

F_{rm} = Toxicity factor due to restricted motion, $F_{\Delta M}$

F_{O_2} = Toxicity due to 100% O_2 at 5 psi

F_{fat} = Toxicity factor due to fatigue, $F_{\Delta F}$

F^*_{int} = Toxicity factor from interaction of the factors = $f_1 \times f_2 \times f_3 \ldots f_n$

and where

f_1 = toxicity above that from intermittent 8-hr exposure and that from 3-fold the dose

f_2 = toxicity from combination of O_2 toxicity and toxic substance

f_3 = toxicity from effect of O_2 on fatigue

Since the space cabin atmosphere, in the near future at least, will range from 5 to 7 psia, the $F_{press} = 3$ appears adequate to cover the fact that lung absorption of gases is by simple diffusion and accordingly is directly proportional to external pressure (163). As mentioned above, the multiplication of 8 hr/day data for 5 day week by 3 does not give adequate safety in all cases for 24 hr/day continuous exposure. The elusive metabolic interactions determining this exact multiplication factor have been discussed above and elsewhere (71, 200). The usual Q_{10} factor indicates that for every 10°C rise in temperature the metabolic rate of a cell will increase at least 2-fold. Although in general, toxicity increases roughly by this factor as body temperature increases, it is by no means a universal rule (100). The restriction of movement and fatigue may add further stressful conditions to the environment and alter to an as yet unknown degree, the response to some toxic agents in humans (144, 200).

The effects of 5 psia, 100% oxygen may have a profound effect, especially on those agents which can inactivate the anti-oxidant defenses (2, 160, 161). Reduction of tocopherol in the plasma of Gemini astronauts has been reported along with a hemolytic process which may resemble the anemia of acanthocytosis (159). (See Nutrition, No. 14, and Oxygen-CO_2-Energy, No. 10.)

There is some indication in animals that oxygen at 5 psia will synergize with systemic toxic agents such as CCL_4 (122, 194, 203). Species differences are quite marked with the primates being relatively resistant. The synergistic factors for specific agents in humans are still not known. Recent evidence suggests that unknown toxic factors may be present in test chambers or associated with such atmospheres as 70% oxygen-30% nitrogen at 5 psia in the presence of a normal alveolar PO_2 (202).

The interaction factors $f_1 \rightarrow f_n$ are still not clear. The studies of 90 day TLV suggest factors in the range of 2 to 4 of f_1 for some agents. For toxic materials with hemolytic potential f_2 may be as high as 2, and for antioxidants, as low as 1/3. Since there is no evidence that oxygen has a profound effect on fatigue, f_3 will probably be rather close to unity (17, 81, 161).

Calculation of TLV_{space} for 11 compounds by this approach leads to ratios of TLV_{Ind} of TLV_{space}: about 3 to 50 (200). Similar calculations have been made for 95 compounds with this ratio running from 1:1 to 10:1 (86). About 1/2 of the compounds had ratios of 2 to 5:1.

SOURCE OF CONTAMINANT

The sources of contaminants in space operations are man and his activities, materials and outgassing, equipment and processes, and finally, malfunctions and emergencies. Table 13-16 lists those compounds found in space cabins, simulators, submarines, and underwater laboratories.

Human Sources of Contaminants

Principal sources of contaminants from man are expired air, urine, feces, flatus, and perspiration (125, 165, 189, 220). The data presented below can be used for waste management analysis.

The primary components of expired air influencing toxicity are CO_2, H_2O, and carbon monoxide from porphyrin metabolism (188, 206). The excretion of water in sweat, respiration and urine of man has been covered in Water, (No. 15).

The composition and daily output of urinary components are summarized in Table 13-3a.

The composition and daily output of fecal components are summarized in Table 13-3b. The weight of feces on mixed diets varies from 0.13 to 0.5 lbs/day wet weight (160 to 250 gm/day and from 0.06 to 0.17 gm/day dry weight (25-75 gm/day (165). The higher the vegetable content, the higher the weight of fecal residue.

Table 13-4 presents the amino- and fatty acid residues of feces.

Figure 13-5 presents caloric output in feces, gaseous elaboration of stored feces, and flow rates of urinary output.

Table 13-6 represents the flatal output of man under different conditions. The nitrogen data represents all materials not included in tests for the other gas. Traces of carbon monoxide are present in this fraction.

The composition of typical sweat output depends on state of acclimatization of man (11). Table 13-7 presents the range of output.

Table 13-3

Composition of Human Urine and Feces

(After Roth[165])

a. Urine

Urine has a specific gravity of 1.002 to 1.035 and a pH of 4.6 to 8.0. The solid contents shown in the table are recorded as mg/24 hours.

	Mean Values					Range
	Altman and Dittmer, eds. (4)	Long (116)	Sunderman and Boerner (201)	Hawk and Bergheim (82)	Diem, ed. (47)	
Solids			60,000.	60,000.		55,000-70,000
Electrolytes						
Aluminum	.077	.078	-	-	-	0.049-0.112
Arsenic	.0231	-	-	--	-	0-0.091
Bicarbonate	140.0	-	-	-	-	35-840
Bromine	-	2.1	-	-	-	0.840-7.70
Calcium	231.0	-	-	200.0	-	43.0-581.0
Chloride (as NaCl)	12,000.	-	-	-	7,638.	7,600-15,000
Chlorine	7,000.	-	-	-	-	2,800-12,600
Copper	0.035	-	-	-	0.018	0-0.049
Fluorine	1.540	-	-	-	-	0.30-7.0
Iodine	-	-	-	-	-	0.007-0.490
Iron	0.490	-	-	-	0.045	0.02-1.1
Lead	0.028	0.035	-	-	-	0.004-0.15
Magnesium	94.5	-	-	150.	103.	29.4-307
Manganese	-	-	-	-	-	0.007-0.098
Nickel	-	0.15	0.15	-	-	0.140-0.280
Phosphorus (as P)	-	-	-	1,100.	1,100.	700-1,600
Inorganic	840.	-	-	-	-	700-1,300
Organic	9.17	-	-	-	-	6.23-13.09
Potassium	2,380.	-	-	2,000.	2,740.	1,120-3,920
Selenium	0.035	-	-	-	-	0-0.140
Silicon	9.10	-	-	-	-	420-14.0
Sodium	4,200.	-	--	4,000.	4,615.	1,750-6,580
Sulfur, total	1,120.	-	-	1,000.	-	357-3,400
Inorganic	777.	--	-	800.	-	245-2,700
Ethereal	66.5	-	-	-	-	40-300
Natural	133.	-	-	120.	-	73-400
Conjugated	-	-	-	80	-	80-300
Tin	-	-	-	-	-	0091-.0175
Zinc	.364	-	-	-	0.457	.110-.500
Nitrogen compounds						
Adenine	1.40	1.4	-	-	-	1.1-1.7
Allantoin	11.9	-	-	40.	-	2.8-40
Amino Acids, Total	-	-	1,100.	-	-	1,100-2,800
Free	-	-	500.	-	-	500-1,400
Alanine, Total	38.5	46.	-	-	-	21-71
Amino-adipic acid	-	10.	-	-	-	8-11
Amino-butyric acid	-	10.	-	-	-	Traces-10
Amino-isobutyric acid	-	20.	-	-	-	4-180
Anserine	-	-	-	-	-	5-7
Arginine, Total	31.5	<10.	23.7	-	47.0	<10-56.8
Asparagine	-	54.	-	-	-	34-99
Aspartic acid, Total	119.0	<10.	164.5	-	113.4	<10-258.8
Carnosine	-	-	-	-	-	2-3
Citrulline	63.0	10.	-	-	-	0-196.0
Crystine, Total	119.0	10.	-	-	87.7	10-200
Glutamic acid, Total	-	<10.	351.4	-	249.9	<10-484.7
Glutamine	-	100.	-	-	-	-
Glycine, Total	455.0	132.	-	-	405.0	132-670.6
Histidine, Total	189.0	216.	203.3	-	284.0	65.4-498.8
Hydroxylysine	-	<10.	-	-	-	<10
Hydroxproline, Total	1.40	0.51	-	-	23.05	0.26-1.4
Isolericine, Total	14.0	18.	20.3	-	11.3	6.5-33.4
Leucine, Total	21.0	14.	21.2	-	27.9	11.9-40.0
Lycine, Total	56.0	19.	73.2	-	102.0	7-166.0
Methionine, Total	9.8	10.	8.6	-	6.6	3.8-15.0
1-methylhistidine	-	180.	-	-	-	47-384
3-methylhistidine	-	50.	-	-	-	-
Ornithine	10.5	<10.	-	-	-	<10-10.5

Table 13-3 (continued)

a. Urine (continued)

	Mean Values					Range
	Altman and Dittmer, eds. (4)	Long (116)	Sunderman and Boerner (201)	Hawk and Bergheim (82)	Diem, ed. (47)	
Amino Acids (cont.)						
Phenylalamine, Total	21.0	18.	23.3	-	28.7	9-45.4
Proline, Total	42.7	<10.	42.8	-	43.3	<10-63.0
Sarcosine	-	<10.	-	-	-	<10
Serine, Total	42.0	43.	-	-	-	27-73
Taurine	-	156.	-	-	156.	7.7-294
Threonine, Total	35.0	28.	53.8	-	83.2	14.8-182.0
Tryptophan, Total	28.0	-	41.4	-	22.9	8-86.1
Tyrosine, Total	49.0	35.	52.5	-	55.5	15-103.3
Valine, Total	21.0	<10.	19.8	-	30.1	<10-44.7
Ammonia	-	700.	-	-	-	300-1,100
Bilirubin	49.0	-	-	-	5.	5-49.0
Coproporphyrin I & III	-	-	-	-	-	.0168-0.280
Creatine	56.0	-	-	-	-	0-900
Creatinine	1,610.0	-	-	1,200.	2,145.0	1,000-3,219
Ethanolamine	-	12.2	-	-	-	4.8-22.9
Glycocyamine	-	-	-	-	-	21-67
Guanidine	-	-	-	-	-	10-20
Guanidinoacetic acid	-	-	-	-	30.	14.0-35.0
Guanine	0.42	1.6	-	-	-	0.21-2.0
8-Hydroxy-7-methyl	1.40	1.6	-	-	-	1.1-2.0
7-Methyl	6.30	6.5	-	-	-	5.5-7.8
N^2-Methyl	0.490	0.5	-	-	-	0.4-0.6
Hippuric acid	-	-	-	700.	700.	70-2,500
Histamine	-	-	-	-	-	0.014-0.070
Hypoxanthine	9.80	9.7	-	-	-	5.6-13.3
I-Methyl	0.42	0.4	-	-	-	0.2-0.7
Imidazole derivatives	-	-	-	-	286.1	140.0-300.0
Indoxylsulfuric acid	70.	100.	0	10.	-	5-160.0
Lipoproteins	-	23.5	-	-	-	-
Methionine sulfoxide	-	-	-	-	-	0-21.70
Nitrogen						
Total N	-	-	-	-	15,300.	1,000-21,000
Amino Acid N	-	-	-	200.	349.	100-431
Ammonia N	-	-	-	700.	-	210-1,000
Protein	-	-	-	-	<50.	2.10-80
Albumin						10-100
Purine bases	-	-	10.	-	-	0.01-70.0
6-Succinopurine	0.980	-	-	-	-	-
Urea	-	22,000.	30,000.	-	-	14,000-35,000
Uric acid	140.0	567.0	-	700.	528.	56-1,000
Urobilin	-	-	-	-	-	10-130
Urobilinogen	-	-	-	-	-	0-25.0
Uropepsin(as tyrosine)	-	-	-	-	417.	98-835
Xanthine	6.30	6.1	-	-	-	4.90-8.6
Vitamins						
B_1 (thiamine)	0.21	-	-	-	-	0.042-0.420
B_2 (riboflavin)	0.868	-	-	-	-	0.140-1.680
B_6 (pyridoxine)	-	-	-	-	-	.0056-.1890
B_{12} (cyanocobalomine)	30.8×10^{-6}	31.	-	-	-	16.1×10^{-6}-55.3×10^{-6}
B_c (folic acid)	.00406	-	-	-	-	.0021-0.238
B_x (p-aminobenzoic acid)	-	-	-	-	-	0.140-0.210
C (ascorbic acid)	-	-	-	-	-	5-55
H (biotin)	0.035	-	-	-	-	0.014-0.070
Choline	5.53	-	-	-	-	4.76-9.10
Citrovorum factor	.00259	-	-	-	-	.00161-.00483
Inositol	14.0	-	-	-	-	8-144
Niacin	0.238	-	-	-	-	0.140-1.40
Niacinamide(niotinamide)	1.40	-	-	-	-	0.70-3.50
Pantothenic acid	3.15	-	-	-	-	1.12-7.0
Dehydroascorbic acid	-	5.1	-	-	-	5.1-20.3
Dehydroascorbic + diketogulonic acid	16.1	-	-	-	-	0-89.6

Table 13-3 (continued)

a. Urine (continued)

	Mean Values					Range
	Altman and Dittmer, eds. (4)	Long (116)	Sunderman and Boerner (201)	Hawk and Bergheim (82)	Diem, ed. (47)	
Vitamins (cont.)						
Diketogulonic acid	-	-	-	-	-	9.8-13.30
N'Methylnicotinamide	-	-	-	-	-	2.80-42.0
Pyridoxal	0.07	-	-	-	-	0.49-0.371
Pyridoxamine	0.112	-	-	-	-	0.028-0.210
4-Pyridoxic acid	-	-	-	-	-	0.63-11.20
Trigonelline	-	-	-	-	-	2.10-21.0
Acids						
Acetoacetic acid	2.80	-	-	-	-	2.10-4.20
Carbolic (phenol) Total	-	-	-	-	-	14.0-42.0
Free	-	-	-	-	-	0-3.50
Carbonic acid	189.0	-	-	-	-	147.0-231.0
Citric acid	-	-	-	-	678.	128-1,400
Formic acid	56.0	-	-	-	-	28.0-140.0
Glucuronic acid	-	-	-	-	-	100-1,325
m-Hydroxybenzoic acid	-	-	-	-	-	10-16
m-Hydroxyhippuric acid	-	4-6	-	-	-	2-150
p-Hydroxyphenyl-hydrocrylic acid	-	10.	-	-	-	2-150
Lactic acid	210.0	73.	-	-	-	50-600.0
Oxalic acid	35.0	22.	-	20	-	1-49.0
Oxoglutaric acid	-	22.	-	-	-	20-40
Pyruvic acid	-	-	-	-	100.	2.5-100
Misc. organic compounds						
Acetone bodies, Total	14.0	-	-	-	19.4	2.10-23.5
Amylase (somogyi)	-	-	-	-	-	260-950 units
Cholesterol	-	-	-	-	-	0-4.998
Glucose (true)	-	-	-	-	72.	50-300
Ketones (total)	-	-	-	-	50.5	19.8-81.2
Phenols	-	-	-	200.	437.	200-636
Reducing substances	-	-	-	-	-	490-1,500
Glucose	-	4.3	-	-	-	1-12
Fructose	-	5.	-	-	-	0-5
Arabinose (mgm per 100 ml.)	-	1.5	-	-	-	0-3
Ribose	-	18.7	-	-	-	-
Xylose	-	1.0	-	-	-	0-3
Lactose	-	7.	-	-	-	0-10
Sucrose	-	5.	-	-	-	0-5
Hormones						
Adrenalin	-	.005				.0006-.0115
Aldosterone	.0035	-	-	-	-	.0007-.0091
Androgens	18.20	-				14.0-23.1
Androsterone	3.5	-				2.45-420
Catecholamines (total)	-	.082				.25-.150
Estradiol	-	.002				0-.007
Estriol	-	.006				.001-.012
Estrone	-	.006				0-.011
Etiocholanolone	3.5	-				2.45-4.20
Hydroxysteroids	5.6	-				2.8-11.9
Insulin	-					(0.16-0.4 units)
17-ketogenic adreno-corticoids	14.7	-				10.5-21.7
α-Ketol-steroids	18.2	-				9.1-32.9
Melanocyte stimulating hormone	-	(27.7 units)				(7.5-47.5 units)
Noradrenalin	-	0.027				.015-.050
Parathyroid	-	(60 units)				(47-72 units)
Pregnanediol	0.91	-				0.35-1.40
Tetrahydrocortisol	1.68	-				0.56-3.50
Tetrahydrocortisone	3.78	-				1.40-8.40

Table 13-3 (continued)

b. Feces

The water content of feces ranges between 65 and 85%, and the pH from 6.9 to 7.7. The bulk and solid contents shown in the table are recorded in mg/24 hours unless otherwise noted.

	Mean Values					Range**
	Altman and Dittmer, eds. (4)	Diem, ed. (47)	Sunderman and Boerner (201)	Spector, ed. (195)	Goldblith and Wick (71)	
Bulk	-	-	-	-	150,000	50,000-350,000
Dry matter	-	-		-	27,000	23,500-35,000
Electrolytes						
Aluminum	.0428	-	-	-		.0428-2.9
Arsenic	2.353	-	-	-	-	.071-8.27
Calcium	534.0	640.	640.	549.	1,180.	100.0-1,180
Chloride		90.	-	-	-	14.97-35.65
Cobalt	.0005	-	-	.0005	1.400	.0001-1.400
Copper	1.925	-	-	1.940	1.020	1.020-2.638
Iron	8.556	-	-	8.640	28.80	4.6-100.0
Lead	0.299	-	-	-	-	0-400
Lithium	-	-	-	-	2.600	-
Magnesium	178.2	200.	200.	180.	252.	107-252
Manganese		-	-	4.760	3.430	1.283-8.556
Mercury	.001	-	-	-	-	-
Molybdenum						2-4
Nickel		-	-	0.130	2.900	.0856-10.0
Phosphorus	703.0	510.	-	-	-	506.2-1700
Potassium	470.	470.	470.	482.	291.	291-1037
Silver	.0570	-	-	-	-	-
Sodium	121.2	120.	120.	122.	116.	116-122
Strontium	-	-	-	-	0.590	-
Sulfur, total	142.7	130.0	-	-	-	-
Tin		-	-	-	-	0.5-32.09
Zinc	7.130	-	-	-	-	4.135-10.27
Nitrogen compounds						
Arginine	-	-	-	-	-	1200-2100
Bile pigments	-	-	-	-	150.	-
Histidine	-	-	-	-	-	600-800
Indole	90.	-	-	-	-	60-100
Isoleucine	-	-	-	-	-	1400-2300
Leucine	-	-	-	-	-	1800-2900
Lysine	-	-	-	-	-	1900-2900
Methionine	-	-	-	-	-	500-800
Nitrogen, total	-	-	-	-	1500.	700-2100
Threonine	-	-	-	-	-	1400-2200
Urobilinogen	-	10.	-	-	101.	10-280
Valine	-	-	-	-	-	1500-2600
Misc. organic compounds						
Carbohydrates & derivatives:						
Total reducing sugar	-	-	-	-	-	-
Fiber*	-	-	-	-	-	10-30
Fats & derivatives:						
Total fat	-	-	-	-	4500.	1000-7000
Total fat*	-	-	-	-	-	10-25
Total fat (unsaponifiable)*						0-5
Vitamins						
Vitamin A	-	-	-	-	-	0.17-0.33
p-Aminobenzoic acid	-	-	-	-	0.246	-
B vitamins	-	-	-	-	15.	
Vitamin B_2 (uroflavin)	1.029	-	-	-	-	0.823-1.313
Vitamin B_6	-	-	-	-	-	0.5-0.8
Biotin	-	-	-	-	0.133	.1-.2
B-carotine	-	-	-	-	-	1.7-3.3
Vitamin E	21.	-	-	-	-	-
Folic acid	-	-	-	-	0.304	-
Pantothenic acid	-	-	-	-	2.20	1.8-3.8
Pyridoxin	-	-	-	-	0.38	0.1-0.5
4-pyridoxic acid	-	-	-	-	-	0.5-0.6
Nicotinic acid	-	-	-	-	3.63	3.5-5.5
Thiamine	-	-	-	-	0.548	0.2-0.8
Riboflavin	-	-	-	-	1.020	0.4-1.20

* Per cent of dry weight.

** Extreme values include data of Consolazio, et al. [14].

Table 13-4

Amino and Fatty Acids in Feces

(After Roth[165], adapted from Goldblith and Wick[71])

a. Amino Acid in Fecal Protein

Data recorded as grams of amino acid/16 grams of N

Amino Acids	Determined by Microbiological Assay	Determined by Amino Acid Analyzer
Alanine	-	4.8
Arginine	5.7, 5.7	3.2
Aspartic acid	-	8.5
Cystine	0.60, 0.60, 0.64	-
Glycine	-	3.3
Glutamic acid	-	4.4
Histidine	2.5, 2.5	1.7
Iso-Leucine	6.3, 6.3	3.6
Leucine	7.9, 7.8, 7.3	5.7
Lysine	8.0, 8.7	5.1
Methionine	2.6, 2.7	1.9
Phenylalanine	4.7, 4.7	3.3
Proline	-	3.7
Serine	-	2.8
Threonine	3.7, 3.9	3.3
Tryptophan	0.71, 0.67	-
Tyrosine	1.9, 1.9	3.2
Valine	8.3, 8.8	4.3

b. Comparison of Composition of Bound, Free, and Total Fatty Acids in Fecal Lipid for a Normal Human

Percentage of Acids in C_6 - C_{20} Range

Acid**	Free	Bound	Total
10:0	0.6	0	0.3
12:0	4.3	2.2	3.3
14:0	8.9	4.4	6.6
Branched 15:0	0.7	1.1	0.9
15:0	1.4	1.1	1.2
16:0	55.2	35.3	45.2
Branched 17:0	0.9	1.4	1.2
17:0	0.4	0.8	0.6
18:0	12.9	31.8	22.3
10-Hydroxy 18:0	0.7	0.9	0.8
14:1	0	0	0
16:1	1.4	2.1	1.8
18:1	6.8	10.7	8.7
Isomer 18:1	3.5	6.5	5.0
18:2	1.3	2.8	2.0
18:3	0	0	0
20:3	Trace*	Trace*	Trace*
20:4	Trace*	Trace*	Trace*
Other unsaturated C_{20} acids	Trace*	Trace*	Trace*

*Trace indicates less than 0.5%.

**Number of carbons and double bonds.

Table 13-5

Physical Data: Feces and Urination

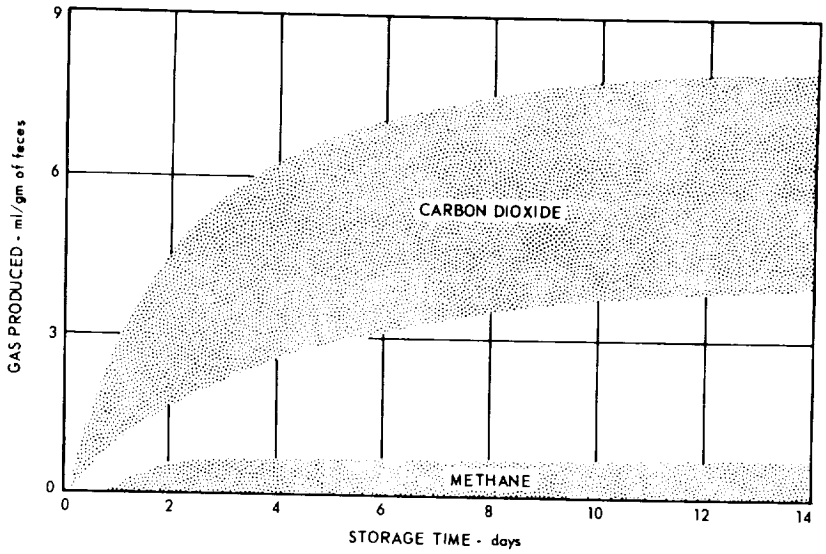
a.

Caloric Value of Feces

	Mean Value	Range
Kcal excreted/day	104	70-142
Kcal/gram, dry weight	4.26	3.48-5.09

(After Wollaeger et al[231])

b.



The shaded areas define the ranges of values for the two major gases produced when feces are stored at 86°F (30°C) for a period of two weeks. Some specimens produced traces of hydrogen and hydrogen sulfide as well.

(After Wheaton et al[228])

c.

Volume, Maximum Rate, and Duration of Urine Flow During the Act of Urination in Adult Men

Subjects	Volume (ml)		Duration (sec)		Maximum rate (ml/sec)		Time to reach maximum rate initially (sec)		Source
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
28 adult males 82 test runs	269	65-580	21	9-47	22	5-40	5.7	1-12	Grace et al [22]
141 adult males, bladder vol >200 ml	-	-	-	-	-	13-45	-	-	Holm [30]
	310	-	-	-	20	-	-	-	Ross [48]
	520	-	-		24	-	-	-	Ross [48]

(After Roth[165])

Table 13-6

Generation and Composition of Flatus

(After Roth[165], adapted from Kirk[104])

a. Flatus Generation*

Specimen	Volume		Source
	Mean ml/day	Range ml/day	
Estimated average volume of discharged gas	1000	-	Clemedson [12]
Discharged gas; 47 normal individuals on ordinary (cabbage free) diet. Single emissions ranged between 25 and 100 ml.	825	100-2800	Kirk [34]
Single discharge 50-500 ml.	1000	-	Fries [19]
Normal average quantity passed daily; five subjects.	524	-	Beazell [6]
Five male medical students unbothered by flatulence; quantities equally divided between day and night.		380-655	Davenport [15]
From control volume of 17 ± 10cc per hr. to 203 ± 87cc per hr. for five men changing from control volume to a pork and beans or dried lima bean diet; (25-50% of calorie intake) for two weeks.		240-4872	Davenport [15]
	2000		Mattoni [39]

* Emitted flatus, not gas formed in stomach, small intestine, or colon; not eructed gas.

b. Chemical Composition of Flatus*

	Cabbage Free Diet, 1943-44 20 individuals		Cabbage & Milk Free Diet, 1945-46 25 individuals	
	Mean %	Range %	Mean %	Range %
Carbon dioxide	9.0	1.2-15.0	9.7	0.7-24.7
Oxygen	3.9	0.0-15.7	5.5	0.5-20.0
Methane	7.2	0.0-30.3	3.1	0.0-21.4
Hydrogen	20.9	3.1-34.0	12.0	0.4-36.5
Nitrogen	59.0	39.7-88.2	70.0	24.7-87.7
Hydrogen sulfide	.0003	0.0-.0017	.0002	0.0-.0003

*Samples obtained by rectal catheterization.

Table 13-7

Composition of Sweat

(After Roth[165], adapted from Altman and Dittmer, eds.[4] and Spector, ed.[195])

	Mean	Range
	mg/100 ml of sweat	
Water	-	99.0-99.5%
Solids, total	-	1.174-1.597%
Electrolytes		
Calcium	2.1	1-8
Chloride	-	30-468
Copper	0.006	0.006-7.5
Iodine	0.0009	.0005-.0012
Iron	0.027	.022-0.2
Magnesium	0.2	.004-4.5
Manganese	0.006	.002-7.4
Phosphorus	0.5	.003-2.0
Potassium	-	21-126
Sodium	-	24-312
Sulfur	-	0.7-7.4
Nitrogen Compounds		
Amino Acids		
Arginine	13.6	5.8-21.4
Histidine	8.	4.25-14.00
Isoleucine	2.27	1.0-3.73
Leucine	2.69	1.2-4.2
Lysine	2.26	1.4-3.38
Phenylananine	2.19	1.0-3.5
Threonine	5.38	1.7-9.1
Tryptophan	1.12	0.4-1.85
Tryosine	3.15	1.2-5.45
Valine	2.96	1.5-4.5
Creatinine		0.1-1.3
Urea		12-5.7
Uric Acid	0.16	0-2.5
Nitrogen		
Total N	33.2	27-64
Non-protein N	31.	27-64
Amino acid N	2.8	1.1-10.2
Ammonia N	-	2.5-35.0
Urea N	-	5-39
Misc. organic compounds		
Ascorbic acid	-	0-.002
Carbolic acid(phenol)	-	2-8
Lactic acid	-	45-452
Corticoids	-	.004-.008
Sugar (as glucose)	-	0.1-40
Vitamins		
B_1 (thiamine)	.00015	0-.006
B_2 (riboflavin)	.0005	.0-.0005
B_6 (pyridoxine)	-	.0004-.00017
B_c (folic acid)	.0006	.00053-.00088
B_x (p-aminobenzoic acid)	.00024	.00008-.00170
C (as dehydro-ascorbic acid)	.0705	
Choline	.0071	.0003-.0071
Inositol	.021	.015-.036
Niacin (nicotinic acid)	-	.0017-.022
Pantothenic acid	.0038	.0015-.0077

The range of saliva output in resting, unstimulated man is 42 to 83 ml/hr (47). When stimulated by chewing paraffin, the output may be raised to about 190 ml/hr with some individuals reaching up to 300 ml/hr (116, 219).

The composition of saliva is noted in Table 13-8.

Data on the generation of hair is noted in Table 13-9a and the composition of hair is noted in Table 13-9b. Differences in composition vary with hair color and race. The generation and composition of nails is noted in Table 13-10; and the generation and composition of skin and sebum, in Table 13-11. The composition of skin secretions are noted in Figure 13-12.

The composition of tears and wax are noted in Figure 13-13. The composition of semen is available (165).

Table 13-14a presents the total waste accumulated from humans per man/day. Data for waste output after prototype Apollo nominal and contingency diets are presented in Figure 14-14b. A list of human effluents according to chemical grouping has also been compiled as shown in Tables 13-14b and c.

Cooking may release such toxic materials from foods themselves (43) or conversion products such as acrolein and formaldehyde. Toiletry, soaps, and hair tonics are also sources of ethereal compounds to be avoided. Microorganisms from humans will be covered below.

Materials and Machines

Compounds of relatively high vapor pressure are outgassed from solid materials and from the hydrocarbon lubricants and operating fluids of machines. They originate from such sources as plastics, toilet articles, lubricating compounds, insulations, paints, cements, and residual solvents from degreasing treatments. Aliphatic and olefinic hydrocarbons may originate as impurities in breathing oxygen. The presence of these compounds in compressed gases stems from the cracking of hydrocarbon compressor oils. The various Freons and Coolanols are used as refrigerants or are present as impurities in refrigerants.

Lists of non-metallic materials currently being used in manned spacecraft are available at the NASA Manned Spacecraft Center in Houston, Texas (72, 79). Agents used in plastic manufacture are also available (131).

The rate of outgassing for various spacecraft materials is under study (57, 90, 141, 149, 203 205). Unfortunately, the oxygen content and temperature of the atmosphere alters the rate and nature of gas-off products. Intermittent purging of the atmosphere is also a variable to be considered in this regard. Compounds continue to be outgassed after 90 days (203).

Table 13-15 lists in alphabetic order chemicals or chemical groups which have been identified as contaminants associated with Projects Gemini and Mercury or with the nuclear submarine environment (173, 212) or anticipated as an agent from fire or other emergencies. Unless otherwise stated, the

Table 13-8

Composition of Saliva

(After Roth[165])

All data recorded as mg/100 mg of saliva unless otherwise noted.

	Mean Values		Range
	Diem, ed. (47)	Altman and Dittmer, eds. (4)	
Water	95.5		
Total solids	-	581.0 (P)*	386-860 (P)
Electrolytes			
Bicarbonate	-	39.294	21.228-65.27
"	-	96.014 (P)	49.532-118.767 (P)
Bromine	-	-	0.02-0.71
Calcium	-	5.8	4.5-10
"	-	5.5 (P)	3.5-9.2 (P)
Carbon dioxide	-	12.	5-25 (vol %)
"	-	25. (P)	8-44 (vol %) (P)
Chloride	102.8	60.025	40.4-165.2
"	-	41.89 (P)	41.89-62.835 (P)
Cobalt	.00704	.00244 (P)	0-.01253 (P)
Copper	.0256	.0063	.002-.0256
"	-	.0259 (P)	.010-.0475 (P)
Fluorine	-	-	.010-.020
Iodine	-	-	0-.350
Magnesium	-	1.409	.3888-2.576
Phosphorus, total	20.4	24.4	12.0-28.8
Organic	5.5	5.5	0-13.3
Inorganic	14.9	14.9	7.4-21.7
Potassium	77.0	80.3	46.4-148
"	-	78.0 (P)	50-95
Sodium	-	23.2	8-56
"	-	57.3 (P)	19-133
Sulfur	7.6	-	-
Thiocyonate	-	13.4	3.1-33.0
Nitrogen compounds			
Ammonia	-	4.42	2-10
"	-	5.95 (P)	1.56-12.07
Amino acids			
Alanine	-	1.2	0.5-2.9
Arginine	-	-	3.3-10.0 (P)
Aspartic acid	-	0.15	0.13-0.33
Cystine	-	-	0.16-0.45 (P)
Glutamic acid	-	1.2	0.5-1.3
Glutamic acid	-	-	3.0-12.6 (P)
Glycine	-	1.4	0.5-3.6
"	-	-	1.9-15.5 (P)
Histidine	-	-	0.35-2.00 (P)
Isoleucine	-	-	0.2-0.9 (P)
Leucine	-	-	0.025-0.300 (P)
Lycine	-	0.7	0.15-1.50 (P)
"	-	-	0.4-1.5 (P)
Methionine	-	-	0.005-0.010 (P)
Phenylalanine	-	-	0.6-2.5 (P)
Proline	-	-	0.35-1.50 (P)
Serine	-	0.66	0.33-1.20
"	-	-	1.0-1.8 (P)

*(P) Paraffin stimulated saliva

Table 13-8 (continued)

All data recorded as mg/100 mg of saliva unless otherwise noted.

	Mean Values		Range
	Diem, ed. (47)	Altman and Dittmer, eds. (4)	
Nitrogen compounds (cont.)			
Threonine	-	-	0.4-5.6 (P)*
Tryptophan	-	-	0.2-0.9 (P)
Tyrosine	-	-	0.2-1.0 (P)
Valine	-	-	0.7-2.2 (P)
Creatinine	-	0.35 (P)	0.275-0.455 (P)
Histamine	.01456	-	.01065-.01810
Mucin	-	250.	80-600
"	-	270.	-
Nitrogen			
Total nitrogen	-	90.0 (P)	36.1-125.3 (P)
Ammonia nitrogen	-	3.8	0.5-9.9
Non protein nitrogen	-	36.4	8.2-62.4
Protein nitrogen	-	63.6 (P)	22.9-88.2 (P)
Protein, total	262.	386.	0-630
"	-	242. (P)	140-527 (P)
Urea	-	12.7	8.2-18.1
"	-	8.8 (P)	0-14.3 (P)
Uric acid	15.	1.5	0.5-15
"	-	4.8 (P)	1.5-8.7 (P)
Misc. organic compounds			
Cholesterol	-	7.5	3-15
Citric acid	-	1.05 (P)	0-1.92
"	-	-	0.20-3.15 (P)
Glucose	-	19.6	11.28-28.08
"	-	20.7 (P)	14.04-30.00 (P)
Lactic acid	-	1.53	1.53-10
Vitamins			
B_1 (thiamine)	-	.0007	-
"	-	-	.0002-.0014 (P)
B_2 (riboflavin)	-	.0050	-
B_6 (pyridoxine)	-	.0006 (P)	.0001-.0017 (P)
B_{12} (cyanocobalamine)	-	.00033 (P)	.00014-.0005 (P)
B_c (folic acid)	-	.0024 (P)	.0003-.0075 (P)
Choline	-	0.65	0.47-0.99
"	-	1.62	0.62-3.64
Niacin (cicotinic acid)	-	.0115 (P)	.00234-.04090 (P)
Pantothenic acid	-	.0088 (P)	.0012-.0190 (P)
C (ascorbic acid)	0.218	.007 (P)	0.058-0.378
"	-	-	0-0.372 (P)
H (biotin)	-	.0008	-
K	-	.0015	-
Enzymes			
Ptyalin	-	-	0-300
Cholinesterase	-	0.33 (P)	0.23-0.43 units/liter[4] (P)
Esterase, total	-	0.34 (P)	0.12-0.65 units/liter[5] (P)
B-Glucuronidase	-	-	170-1750 units/liter[6] (P)
Lipase	-	1.42 (P)	0.25-2.58 units/liter[7] (P)
Lipozyme	-	670. (P)	250-1360 units/liter
Phosphatase, acid	-	4.23 (P)	2.5-7.7 units/liter[8]

* (P) Paraffin stimulated saliva.

Table 13-9

Generation of Hair

a. Growth Rate of Hair

Type	Growth Rate	
	mg/day	mm/day
Facial hair; male Caucasian.	150-200	
Facial hair; adult Caucasian males, age 30-60, electric shaver without preparatory shaving lotion. Mean: 72.3 mg/day	52.1-96.2	
Facial hair; adult Caucasian males, ages 30-60; electric shavers with preparatory pre-shave lotions. Mean: 114.6 mg/day	50.2-153.8	
Facial hair; adult Caucasian males, ages 30-40.	35-40	
Facial hair.	300	
Scalp hair, adult men.		0.305
Hair above ear, adult men.		0.331
Axillary hair; adult men.		0.356
Thigh hair; adult men.		0.153
Chin hair (during summer), adult men.		0.535
Chest hair; adult men.		0.280
Pubic hair, adult men.		0.076
Scalp hair.		0.30-0.5
Head hair.		0.385
Arm hair.		0.214
Facial hair.		0.300-0.500
Scalp hair, 28-yr-old man.	31.6	
Facial hair, 28-yr-old man.	26.9	
Body hair, 28-yr-old man.	22.8	

(After Roth[165] from the data of Cohen[34], Mattoni and Sullivan[125], Spector[195], and Voit[215])

Table 13-9 (continued)

b. Composition of Hair

All data recorded as mg/100 gm of dry, fat-free material.

	Mean Values		Range	
	Altman and Dittmer, eds.[4]	Spector, ed.[195]	Other	Mattoni and Sullivan[125]
Water	4.2	4.1		
Electrolytes				
Aluminum	2×10^{-6} -3.6	3.2		
Arsenic	0.22	0.22		
Boron	-	-		0.2-0.8
Bromine	-	-		0.2-0.7
Calcium	-	20.8		18-490
Chromium	0.2	0.2		-
Cobalt	1.4-1.8	1.8		1.4-1.8
Copper	-	10.8		0.7-10.8
Iron	-	14.1		0.8-17.0
Lead	-	4.8		1.7-28.4
Magnesium	1.0-10.1	-		-
Manganese	10^{-6}-4.6	3.8		-
Nickel	-	0.8		0.5-0.8
Phosphorus	-	80.0		65-90
Silicon	-	-		15-360
Silver	0.00045	-		-
Strontium	-	-		0.0000022-0.0091
Sulfur	-	3.8	4.7-5.5 (198)	-
Titanium	-	-		0.00320-0.0064
Uranium	0.0127	-		-
Zinc	-	21.2		0.9-44.4
Organic Compounds				
Pentose	30.0	-		-
Protein	-	91.0		85-91
Sugars	80.0	80.0		-

(After Roth[165])

Table 13-10

Generation and Composition of Nails

(After Roth [165])

a. Generation of Nails

Type	Growth rate (mm/day) Mean	Growth rate (mm/day) Range	Growth rate (gms) Mean	Growth rate (gms) Range	Source
Fingernail, 20 yr tests		0.102-0.132			Bean (13)
Fingernail, age 32	0.123				Bean (13)
Fingernail, age 42	0.111				Bean (13)
Fingernail, age 52	0.105				Bean (13)
Thumbnail, adult	0.095				Spector, ed. (195)
Toenail, adult	0.023				Spector, ed. (195)
Fingernail	0.142		0.010 gm/ day		Mattoni and Sullivan (125)
Thumbnail	0.130				Mattoni and Sullivan (125)
Toenail	0.036				Mattoni and Sullivan (125)
Fingernail, 81 healthy young adults, both sexes		0.063-0.146			Sibinga (215)
Fingernails and toenails, several individuals over a period of many years			2.02 gms/ year		Voit, Part (215)

b. Chemical Composition of Nails

All data recorded as gms/100 gms

	Spector, ed.	Silver and Chiego	Rothman	Others
Water*	0.07-0.72	7-12	-	
Chromium	0.012	-	-	
Zinc	0.011	-	-	
Fat	-	0.76-1.15	-	
Keratin components				
Ash	-	0.042	-	
Carbon	-	48.7	-	
Hydrogen	-	6.59	-	
Nitrogen	-	16.55	14.9	
Sulfur	3.3-3.5	3.92	3.8	
Amino acids				
Arginine	-	10.01	8.5	
Cystine	-	2.31	12.0	10.3 (198)
Histidine	-	0.59	0.5	
Lysine	-	3.08	2.6	
Methionine	-	2.47	-	
Phenylalanine	-	-	2.5	
Tryptophane	-	-	1.1	
Tyrosine	-	-	3.0	

* Hygroscopic nature of keratin causes considerable variation in water content

Table 13-11

Dried Skin and Sebum

(After Roth[165])

a. Loss of Dried Surface Skin

Subject	Mass		Volume	Source
	lbs/man day	gms/man day	ml/man day	
28-yr-old man	.0013	0.57		Voit, Part III (215)
(unspecified)	.0066	3.00	2.8	Mattoni and Sullivan (125)

b. Generation of Sebum

Sebum is fat excreted from both sebaceous glands and keratinizing cells.

Location	Total Saturation Level*	Casual Level**	Source
Forehead	3.38 mg/cm^2	1.77 mg/cm^2	Rothman (167)
Forehead; hundreds of estimates	15.4 mg/40 cm^2 (12 hrs)		Rothman (167) after Serrati (185)
Flexor sides of prearm; hundreds of estimates	4.2 mg/40 cm^2 (12 hrs)		Rothman (167) after Serrati (185)
Forehead; mean value from reports by 11 investigators	2.82 mg/cm^2		Rothman (167)
Forehead; mean of 234 estimates in men and women ages 16-60 years.	2.89 mg/cm^2		Kirk (103)
Chest, back and shoulder lipids from T-shirt worn by subjects		54 mg/hr	Powe (147)

* Total, or true saturation levels: surface completely protected from accidental removal of fat.

** Casual level: test site not protected against accidental touching, wiping, or contact with clothing (excretions about one-half quantities of true saturation level).

Table 13-12

Composition of Skin Secretions

a. Major Components of Skin Secretions

	Mean	Range
	gms/100 gms of excretions	
Water	31.7	-
Epithelial cells & protein	61.75	-
Fat	4.16	-
Butyric, Valeric, and Caproic Acid	1.21	-
Ash	1.18	-
Fatty Acids combined	34.6 (Fa)	27.5-41.0 (Fa)
	28.0 (S)	21.0-39.0 (S)
Monoglycerides	3.7	1.8-7.1
Diglycerides	10.1	-
Triglycerides	32.5 (Fa)	14.8-44.0
	44.0 (Fh)	-
	16.0 (S)	16.0-24.8
Waxes (cholesterol esters)	23.7	-
Fatty Acids free	28.3 (Fa)	2.3-38.3
	38.0 (Fh)	-
	33.0 (S)	-
Unsaponifiable matter (total)	30.1 (Fa)	25.1-35.9 (Fa)
	34.0 (S)	29.0-40.0 (S)
Aliphatic alcohols (total)	6.2 (Fa)	4.7-6.9 (Fa)
	9.0 (S)	-
Straight chain	2.4 (Fa)	-
Branched chain	3.8 (Fa)	-
	0.9 (S)	
Cholesterol	4.1 (Fa)	1.2-9.5
	3.5 (Fh)	-
Dihydrocholesterol	0.1 (Fa)	-
Hydrocarbons	8.1 (Fa)	5.0-20.0
	9.0 (S)	-
Paraffins	1.5	1.2-1.9
Phosphatides	0.9 (Fh)	-
Squalene	5.5 (Fa)	5.5-17.3
	7.0 (S)	

Fa: forearm
Fh: forehead
S: scalp

(After Roth[165], adapted from Altman and Dittmer[4], Haahti[74], and Sunderman and Boerner[201])

Table 13-12 (continued)

b. Fatty Acids in Human Skin Lipids

	Free Fatty Acids		Fatty Acids of Waxes & Sterol Esters	
	Mean	Range	Mean	Range
	gms/100 gms of lipid		gms/100 gms of lipid	
Tetradecanoic	5.0	3.8-7.7	7.5	3.5-9.3
Tetradecenoic	5.6	4.3-7.8	2.1	1.3-3.6
Pentadecanoic	3.1	2.2-3.7	6.4	4.4-7.8
Pentadecenoic	7.4	5.7-8.5	2.9	1.8-3.4
Branched Hexacecanoic	4.2	2.6-8.6	-	-
Hexadecanoic	10.5	6.8-13.8	33.5	29.2-42.1
Hexadecenoic	41.5	34.2-49.8	33.4	7.5-21.9
Branched Heptadecanoic	6.6	4.8-9.8	4.6	3.5-6.5
Heptadecanoic	1.1	0.6-1.5	2.8	1.5-5.2
Heptadecenoic	3.8	3.3-4.4	3.4	2.9-3.7
Branched Actadecanoic	1.6	1.6-1.7	1.7	1.5-2.0
Actadecanoic	2.1	1.2-3.1	6.5	3.9-13.7
Actadecenoic	7.1	6.3-7.5	12.2	9.8-13.6

c. Major Alcohol of the Waxes and Sterol Esters of Human Skin Surface Lipids

	Mean	Range
	gms/100 gms of lipid	
Tetradecanol	7.7	6.3-9.6
Hexadecanol	8.7	5.9-10.6
Hexadecenol	1.9	1.0-2.9
Octadecanol	12.7	11.3-14.0
Octadecenol	3.8	3.0-4.6
Eicosanol	10.9	9.8-12.6
Eicosenol	19.7	17.6-22.6
Docosanol	4.8	4.2-5.4
Docosenol	7.6	6.2-9.5
Tetracosanol	4.4	3.0-5.8
Tetracosenol	5.3	3.5-5.8
Cholesterol	13.2	11.7-15.6

(After Roth[165], adapted from Haahti[74])

Table 13-13

Tears and Ear Wax

a. Generation of Tears

The secretion rate of tears ranges from 0.031 to 0.041 gms/hour, as reported by Sunderman and Boerner[201] from collections made over a 16-hour period.

b. Composition of Tears

		Mean Values gms/100 ml of tears
Water	98.2%	
Total Solids	1.8	
Ammonia		5.
Ash		1050.
Chlorides (as NaCl)		658.
Nitrogen, total		158.
Nonprotein N		51.
Potassium as K_2O		140.
Proteins		669.
Albumin		-
Globulin		-
Sodium as Na_2O		600.
Sugar		650.
Urea		30.
Vitamin C		-

(After Roth[165], adapted from Altman and Dittmer[4], Best and Taylor[15], and Sunderman and Boerner[201])

c. Composition of Ear Wax

	Mean gms/100 gms of wax	Range
Total lipids	44.	13-64
Phospholipids	0.5	
Non-saponifiable	3.5	
Saponifiable	5.1	
Protein	24.	15-40
Residue	32.	

Also present are 24 or more branched or unbranched fatty acids, and the amino acids alanine, aspartic acid, glutamic acid, glycine, leucine, serine, threonine, tyrosine, and valine.

(After Roth[165], adapted from Akobjanoff et al[3], Bauer et al[12], Chiang et al[30, 31], and Haahti et al[74])

Table 13-14

Summation of Human Effluents

a. Total Waste Accumulation/Man-Day for Use in Design of Environmental Control Systems*

	UNCONTAINED		CONTAINED	
	WEIGHT	VOLUME	WEIGHT	VOLUME
SOLIDS	(grams)	(ml)	(grams)	(ml)
Misc. Cabin Compounds	0.70	0.72		
Food Spillage (including vomitus)	0.70	0.70		
Desquamated Epithelium	3.00	2.80		
Hair - Depilation loss	0.03	0.03		
Facial Shaving	0.05	0.05	0.25	0.23
Nails			0.01	0.01
Sweat Residue	3.00	3.00		
Sebaceous Residue	4.00	4.00		
Saliva Solids	0.01	0.01		
Mucous Solids	0.40	0.40		
Seminal Residue	0.01	0.01		
Fecal Particles	0.02	0.02		
Micro-organisms	0.16	0.14		
Fecal Solids			20.00	19.00
Urine Solids	0.03	0.02	69.98	65.98
TOTALS	12.11	11.88	89.98	85.98
LIQUIDS				
Fecal Water			100	100
Urine Water			1330	1330
TOTALS			1430	1430
GASES				
Flatus		2,000 ml		
Insensible Water		1,200 ml		
TOTALS		3,200 ml		

* See also Figure 14-14b for wastes during consumption of prototype Apollo diets.

(After General Dynamics[67])

b. The Chemical Effluents of Man and Their Sources

COMPOUND	SOURCE	COMPOUND	SOURCE	COMPOUND	SOURCE
acetaldehyde	D,F,O,U	adenine	D, U	aniline	D
acetamide	D	alanine	D,F,O,U	arabinose	D, O
acetic acid	D, O	aldolase	O	arachidic acid	D
acetic anhydride	D	aldosterone	U	arginine	D,F,O,U
acetoacetic acid	F,O,U	alkaline phosphatase	O	arsenic	F,O,U
acetone	D,F,O,U	allantoin	U	ascorbic acid	O,U
acetonitrile	D, O	allyl alcohol	D	aspartic acid	D,F,O,U
acetophenone	D	aluminum	D,F, U	barium	O
acetychloride	D	aminobenzoic acid	D,F, U	benzalacetone	D
acetylacetone	D, C	aminobutyric acid	D,F	benzene	D
acetylene	D	aminoisobutyric acid	D,F	benzoic acid	D,F, U
acetylcholine	D, O	aminophenol	D	benzyl alcohol	D,F, U
acetylglucosamine	O	ammonia	D,F,O,U	benzylamine	D
acetylnitrate	D	ammonium sulfate	O,U	benzyl chloride	D,F
acetylurea	D, U	amyl acetate	D	bilifuscin	F
acid phosphatase	O,U	amyl alcohol	D	bilirubin	D,F, U
acrolein	D	amylase	F,O,U	biliverdin	F
acrylic acid	D	androsterone	U	biotin	F,O,U

* O - oral, D - dermal, F - fecal, U - urinary

(After Weber[220])

Table 13-14 (continued)

b. The Chemical Effluents of Man and Their Sources (continued)

COMPOUND	SOURCE
boron	F,O
bromine	D,F, U
butyl acetate	F
butyl formate	D
butyraldehyde	D,F,O
butyric acid	D,F, U
calcium	D,F,O,U
calcium carbonate	F,O,U
calcium phosphate	D,F,O,U
calcium sulfate	D,F
capric acid	D,F
caproic acid	D,F
caprylic acid	D,F
carbamic acid	D,F, U
carbamyl chloride	D
carbon dioxide	D, O,U
carbon disulfide	D,F
carbonic acid	D, O,U
carbonic anhydrase	F,O
carbon monoxide	D,F, U
catalase	F
catechol	D
chloroacetone	D,F,O
chloroacetic acid	D,F, U
chlorine	D,F,O,U
chlorobenzene	F,O,U
chlorocarbonic acid	D,F,O,U
chloroprene	D,F
cholesterol	D,F
cholecalciferol	D,F
cholic acid	D,F
choline	D,F, U
cholinesterase	D
chromium	D, O,U
cinnamic acid	D,F
citrulline	D, O,U
cobalt	O
copper	D,F,O
coprostanol	O
creatinine	D,F, U
coproporphyin I and III	D,F, U
cyanamide	D, U
cyanic acid	D,F,O,U
cyanocobalamine	D
cyclopropane	D
cyclohexyl amine	D
cysteine	D,F,O,U
cystine	F, U
dehydroascorbic acid	D,F
dehydrobilirubin	D,F,O,U
dehydrocholesterol	O,U
deoxycholic acid	U
diacetyl	D,F
diazomethane	U
F,O	
D,F,O,U	
F	
D,F,O,U	
F, U	
D,F, U	
D, U	
F,O,U	
D	
F	
D, U	
D,F, U	
D, U	
D,F	
D,F, U	
D,F	
D, O,U	
D	

b. The Chemical Effluents of Man and Their Sources (continued)

COMPOUND	SOURCE	COMPOUND	SOURCE	COMPOUND	SOURCE
dichloroethylene	D	ethyl butyrate	D,F	etiocholanolone	U
diethyl ketone	D, O	ethyl carbonate	D	fluorine	D, O,U
diketogulonic acid	O,U	ethyl chloride	D, O	folic acid	D, O,U
dimethylamine	D, U	ethylene	D,F	folinic acid	F, U
dimethyl sulfide	D, O	ethylene chlorohydrin	D	formaldehyde	D,F,O,U
diphenylamine	D	ethylene chloride	D, U	formamide	D, O
epicoprostanol	F	ethylene diamine	D,F	formic acid	D,F, U
epiguanine	U	ethylene glycol	D	formic ether	D, U
epinephrine	D, O,U	ethylene oxide	D	formyl chloride	D
estradiol	U	ethyl ether	D, O,U	fructose	O,U
estriol	U	ethyl formate	D,F	fucose	D, O
estrone	U	ethylidene chloride	F	furan	D
ethane	D, O	ethyl iodide	D,F	galactosamine	O
ethane thiolic acid	D,F	ethyl mercaptan	D,F, U	galactose	D, O
ethane sulfonyl chloride	D, U	ethyl nitrate	D,F	gluconic acid	F,O
ethyl acetate	D,F	ethyl nitrite	D	glucosamine	D,F,O
ethyl alcohol	D,F,O,U	ethyl propionate	D	glucose	D,F,O,U
ethylamine	D, O	ethyl propyl ether	D, U	glucuronidase	O
ethyl bromide	D	ethyl sulfide	D,F, U	glutamic acid	D,F,O,U

Table 13-14 (continued)

b. The Chemical Effluents of Man and Their Sources (continued)

COMPOUND	SOURCE	COMPOUND	SOURCE	COMPOUND	SOURCE
glutamine	U	hydrogen	D,F,O	isocyanic acid	D, O
glutaric acid	D	hydrogen bromide	D, U	isodecanol	D
glyceraldehyde	D,F,O	hydrogen chloride	D, O,U	isoleucine	D,F,O,U
glycerol	D,F	hydrogen phosphide	F	isophthalic acid	D
glycine	D,F,O,U	hydrogen sulfide	D,F	isoprene	D, O
glycoaldehyde	D,F	hydroquinone	D	isopropyl acetate	D
glycolic acid	F	hydroxybutyric acid	F, U	isopropyl alcohol	D, O,U
glycolic aldehyde	D,F	hydroxyproline	D, O,U	isopropyl amine	D
glyoxal	D	hydroxystearic acid	F	isovaleraldehyde	D
glyoxalic acid	D	hypoxanthine	U	kynurenin	F
guanidine	D,F	iminodiacetic acid	O,U	lactase	F
guanine	D,F, U	indole	D,F	lactic acid	D,F,O,U
guanidinoacetic acid	U	inositol	D, O,U	lauric acid	D,F
heteroxanthine	U	indoxyl potassium sulfate	U	lead	F, U
hippuric acid	U	indoxylsulfuric acid	U	leucine	D,F,O,U
histamine	F,O,U	invertase	O	linoleic acid	F
histidine	D,F, U	iodine	D, O,U	lipase	F,O,U
hyaluronidase	O	iron	D,F,O,U	lithium	F,O
hydrocyanic acid	D,F,O,U	isobutyraldehyde	D	lithocholitic acid	D,F

Table 13-14 (continued)

b. The Chemical Effluents of Man and Their Sources

COMPOUND	SOURCE
lysine	D,F,O,U
lysozyme	O,U
magnesium	D, O,U
malic acid	D
malonic acid	D
maltase	F,O
manganese	D,F,O,U
mannose	D, O
margaric acid	F
mesobilirubin	F
mesobiliviolin	F
methane	D,F,O
methionine	D,F,O,U
methionine sulfoxide	F, U
methyl acetamide	D
methyl acetate	D,F
methyl alcohol	D,F,O,U
methyl amine	D, O
methyl bromide	L,F
methyl carbonate	D, U
methyl chloride	D,F,O,U
methyl ether	O,U
methyl ethyl ether	D, O,U
methyl ethyl ketone	D
methyl formate	D
methyl iodide	F,O
methyl isocyanate	D,F,O,U
methyl isothiocyanate	D, O
methyl mercaptan	F
methyl nicotimamide	F
methyl nitrite	F
methyl propyl ether	D,F,O
methyl sulfide	D,F,O,U
methyl thiocyanate	F, U
methyl urea	D
methyl vinyl ether	D,F
methylxanthine	D,F,O,U
methylene chloride	D, O
molybdenum	L,F
mucinase	D, U
myristic acid	D, U
niacin	D, O,U
niacinamide	D, O,U
nickel	D, O
nitric oxide	F
nitrobenzene	D,F
nitrogen	D,F, U
nitrogen dioxide	D,F, U
nitrogen hydrate	D,F, U
nitrogen monoxide	U
nitrogen oxychloride	D
nitrogen tetroxide	D, O,U
nitromethane	D,F,O
nitrophenol	D, O
nondecylic acid	D, O,U
norepinephrine	D
nuclease	U
oleic acid	D,F
ornithine	F, U
oxalic acid	O
	F,O
	D,F,O,U
	F, U
	F,O,U
	D, O
	D,F
	D,F,O,U
	D, O
	F
	D, O
	D, O
	D
	D
	D,F
	F
	U
	F
	F
	D, O,U
	D, U

b. The Chemical Effluents of Man and Their Sources (continued)

COMPOUND	SOURCE	COMPOUND	SOURCE	COMPOUND	SOURCE
oxamide	D,F	phenylalanine	D,F,O,U	propyl formate	D,F
oxygen	D,F,O,U	phosphorus	D,F,O,U	propyne	D
oxyphenyl propionic acid	F	phosphorus tetroxide	F	purine	D,F, U
palmitic acid	D,F	potassium	D,F,O,U	pyridine	D,F
pantothenic acid	D,F,O,U	potassium carbonate	D,F,O	pyridoxal	D, U
paracresol	F	potassium chloride	D,F,O,U	pyridoxamine	O,U
parahydroxyphenylacetic acid	U	pregnanediol	U	pyridoxic acid	U
parahydroxyphenylpropionic acid	U	pregnanetriol	U	pyridoxine	D,F,O,U
parahydroxyphenylpyruric acid	U	probilifuscin	F	pyroncomane	F
paraxanthine	U	proline	D,F,O,U	pyrone	D
paracresolsulfuric acid	U	propentdyopent	F	pyrrole	D,F
pelargonic acid	F	propionaldehyde	D, O	pyruvic acid	D, O,U
penta decanoic acid	F	propionamide	D,F	rennin	F
pepsin	O,U	propionic acid	D,F, U	resorcinol	D,F
phenetole	D	propionyl chloride	D	riboflavin	D,F,O,U
phenol	D, U	propyl acetate	D	ribose	D, O
phenol oxidase	O	propyl alcohol	D, O,U	rubidium	O
phenolphthalein	D,F	propylene	D	sarcosine	D,F, U
phenolsulfuric acid	U	propylene oxide	D	selenium	O,U
phenyl acetate	D	propyl ether	D	serine	D,F, U

Table 13-14 (continued)

b. The Chemical Effluents of Man and Their Sources (continued)

COMPOUND	SOURCE
silicon	U
skatole	D,F
skatoxylsulfuric acid	U
sodium	D,F,O,U
sodium carbonate	F,O
sodium chloride	D,F,O,U
sodium phenate	D
sodium sulfate	D, O
sphingosine	F
squalene	D,F
stearic acid	D,F
strontium	F,O
succinic acid	D
succinopurine	U
sucrase	F
sucrose	D, O
sulfur	D,F, U
sulfur dioxide	D, U
sulfur trioxide	U
sulfuryl chloride	F
taurine	D, O,U
taurocholic acid	F
tetrahydrocortisol	U
tetrahydrocortisone	U
tetrahydropyran	D
theophylline	U
thiamine	D,F,O,U
thiazole	D
thionyl chloride	F
thiophene	D
thiourea	D, U
threonine	D,F,O,U
tin	O,U
titanium	O
toluene	D,F
toluidine	D
tridecoic acid	F
trigonelline	U
trimethylamine	D, O
trypsin	F, U
tryptophan	D,F,O,U
tyramine	F
tyrosine	D,F,O,U
undecyclic acid	F
urea	D, O,U
urease	O
uric acid	D, O,U
urobilin	F, U
urobilinogen	F, U
valeric acid	D,F
valine	D,F,O,U
vinyl alcohol	D
vinyl chloride	D
water	D,F,O,U
xanthine	U
xylose	D, O
zinc	O,U

Table 13-14 (continued)

c. Trace Constituents in Effluents of Man According to Organic or Biochemical Groups

CHEMICAL GROUP	NUMBER OF COMPOUNDS
Acid derivatives (except esters)	21
Alcohols	16
Aldehydes and Ketones	17
Amino acids	22
Aromatics	34
Bile derivatives	14
Carbonic acid derivatives	12
Dicarboxylic acids	8
Elements	32
Enzymes	23
Esters	13
Ethers	9
Halongenated hydrocarbons	12
Hetercyclics	19
Hormones	11
Hydrocarbons	12
Inorganics	31
Monocarboxylic acids	31
Nitrogen derivatives	24
Saccharides	11
Sulfur derivatives	13
Vitamins	15
Total	400

Total sources: Dermal - 271
Fecal - 196
Oral - 149
Urinary - 183

Table 13-15

Recommended Limits for Contaminants Already Found and Anticipated in Space Cabins and Submarines

Toxic Hazard Rating

1. SLIGHT: readily reversible effects
2. MODERATE: not severe enough to cause death or permanent injury
3. HIGH: may cause death or permanent injury after very short exposure to small quantities

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Acetaldehyde		200	General narcotic action on the CNS. Irritating to the eyes. High concentrations cause headache and stupefaction.	(177) -p.384
Acetic Acid		10	Irritating to the eyes and mucous membranes. Penetrates the skin easily and can cause dermatitis and ulcers.	(177) -p.386
Acetone		2000 for 24 hrs. 300 for 90 days	Narcotic in high concentrations	(135, 136)
Acetylene	Systemic 1-2	2500 for 24 hrs. 2500 for 90 days	When mixed with oxygen, in proportions of 40% or more, a narcotic. A simple asphyxiant.	(135, 136)
Acrolein		0.1	Particularly affects the membranes of the eyes and respiratory tract.	(177) -p.397
Acrylic Acid	Acute Local: 3		Irritant by ingestion and inhalation	(177) -p.398
Adipic Acid			Details unknown; toxicity probably slight.	(177) -p.399
Alkyl Nitrate			No physiological information available.	
Alkyl Siloxanes			No specific physiological information available. Generally siloxanes are eye irritants.	
Allyl Alcohol		2	Irritation of skin, eyes and mucous membranes. Systemic poisoning is possible.	(177) -p.404
Alumino Silicates		N	No physiological information available.	
Ammonia		400 for 1 hr. 50 for 24 hrs. 25 for 90 days		(135, 136)

*Unless otherwise specified as provisional limits under normoxic conditions by the NAS-NRC(136) the limits are given as TLV (Earth equivalent), covering exposures for 8 hrs/day, 5 days per week at standard temperatures and pressures.

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Ammonia, Anhydrous		50	Irritating to eyes and mucous membranes of respiratory tract. Irritation of the skin may occur, especially if it is moist.	(177) -p.424
Amyl Alcohol	Local:1 Systemic: 2-3		Vapor may be irritating to the eyes and upper respiratory tract.	(177) -p.438
Benzene		100 for 24 hrs. 1 for 90 days	Exposure to high concentrations (3,000 ppm) may result in acute poisoning; narcotic action on the CNS. A definite cumulative action on bone marrow from 100 ppm exposures.	(135, 136)
Bisphenol A		5	As phenol.	(41)
1-3 Butadiene		1000	Vapors are irritating to eyes and mucous membranes. Inhalation of high concentrations can cause unconsciousness and death. If spilled on skin or clothing, it may cause burns or frostbite.	(177) -p.533
Butane	Systemic: 1-2		Simple asphyxiant. Produces drowsiness.	(177) -p.533
2 Butanone		100 for 60 min. 20 for 90 days 20 for 1000 days	Irritation of mucous membranes	(136)
Butene-1	Systemic: 2		An anesthetic and asphyxiant.	(177) -p.545
CIS-Butene-2			Details unknown. May act as a simple asphyxiant.	(177) -p.535
Trans-Butene-2			Toxicity unknown.	(177) -p.535
(N.-) Butyl Alcohol		100 (TLV) 10 for 90 days 10 for 1000 days	Irritation of the eyes with corneal inflammation, slight headache, slight irritation of the nose and throat and dermatitis of the fingers. Keratitis has also been reported.	(136, 177) -p.538
Butyraldehyde	Local:1-2 Systemic: 2		Local: Irritant; Ingestion, Inhalation. Systemic: Ingestion, Inhalation.	(177) -p.555
Butyric Acid	Local:1 Systemic: 1		Local: Irritant; Ingestion, Inhalation. Systemic: Ingestion, Inhalation.	(177) -p.555

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Caprylic Acid			Details unknown. Irritating vapors can cause coughing. Experimental data suggest low toxicity.	(177) -p. 572
Carbon Dioxide		25,000 for 1 hr. 10,000 for 24 hrs. 5,000 for 90 days	Inhalation. (See Oxygen-CO_2-Energy, No. 10.)	(136)
Carbon Disulfide		20	Narcotic and anesthetic effect in acute poisoning, with death following from respiratory failure. Sensory symptoms precede motor involvement. Liver, kidney and heart may be damaged.	(177) -p. 575
Carbon Monoxide		50 200 for 1 hr. 200 for 24 hrs. 5 for 90 days 15 for 1000 days	Effect is predominantly one of asphyxia, due to formation of irreversible carboxyhemoglobin in blood. 1,000 to 2,000 ppm for 1 hr. is dangerous, 4,000 ppm is fatal in less than 1 hr.	(135, 136)
Carbon Tetrachloride		10	Narcotic action. High concentrations produce unconsciousness, followed by death. After effects may include damage to kidneys, liver and lungs. 1,000 to 1,500 ppm for 3 hrs. may cause symptoms.	(177) -p. 578
Carbonyl Fluoride		25 for 60 min.	Pulmonary irritation (animals)	
Chlorine		1 1 for 24 hrs. 0.1 for 90 days	Irritating to mucous membranes. If lung tissues are attacked, pulmonary edema may result.	(135, 136)
Chlorobenzene		75	Slight irritant. May cause kidney and liver damage upon prolonged exposure.	(177) -p. 602
Chloroform		5 for 90 days 1 for 1000 days	Fatty infiltration of liver at toxicological threshold.	(136)
Chloroprene		25	Asphyxiant. Vapor is a central system depressant. Lowers blood pressure. In animals causes severe degenerative changes in the vital organs, especially kidneys and liver.	(177) -p. 613

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Chloropropane			No physiological information available, but should have toxic properties similar to ethyl chloride.	
Cupric Oxide	Local:1 Systemic: 1-2		As the sublimed oxide, copper may be responsible for one form of metal fume fever.	(177) -p.633
Cyanamide	Systemic: 1-2		Causes an increase in respiration and pulse rate, lowered blood pressure and dizziness. There may be a flushed appearance of the face. Does not contain free cyanide.	(177) -p.648
Cyclohexane		300	May act as a simple asphyxiant.	(177) -p.652
Cyclohexanol		50	Local: irritant; ingestion, inhalation. Systemic: ingestion, inhalation, skin absorption.	(177) -p.652
Dichloromethane		25 for 90 days 5 for 1000 days	Reduction of voluntary activity at threshold (in animals).	(136)
2,2 Dimethylbutane			Toxicity: details unknown.	(177) -p.738
1,1 Dimethylcyclohexane			No physiological information available.	
Trans-1,2 Dimethylcyclohexane			No physiological information available.	
Dimethyl Hydrazine		0.5	Can be absorbed through intact skin. May result in convulsive siezures, pulmonary edema and hemorrhage.	(177) -p.746
Dimethyl Sulphide			Toxicity: details unknown. Probably highly toxic.	(177) -p.1007
1-4 Dioxane		100 10 for 90 days 2 for 1000 days	Repeated exposure has resulted in human fatalities, the affected organs being the liver and kidneys. Death results from acute hemorrhagic nephritis. Brains and lungs show edema.	(177,136) -p.760
Epichlorohydrin		5	In acute poisoning, death is the result of respiratory paralysis. Chronic poisoning is the result of kidney damage.	(177) -p.784

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Ethyl Acetate		400 40 for 90 days 40 for 1000 days	Irritating to mucous surfaces. Prolonged or repeated exposures cause conjunctival irritation and corneal clouding. High concentrations are narcotic and can cause congestion of the liver and kidneys.	(177, 136) -p.789
Ethyl Alcohol		500 for 24 hrs. 100 for 90 days	No cumulative effect. Irritating to eyes and mucous membranes of upper respiratory tract. Narcotic properties.	(135, 136)
Trans-1, ME-3 Ethylcyclohexane			No physiological information available.	
Ethylene	Acute Systemic: 2		High concentrations cause anesthesia. A simple asphyxiant.	(177) -p.800
Ethylene Dichloride		50	Irritating to eyes and upper respiratory passages. Vapor causes a clouding of the cornea which may progress to endothelial necrosis. Strong narcotic action. Edema of the lungs in animals.	(177) -p.803
Ethylene Glycol	Local:0-1 Systemic:	0.2 100 for 60 min.	If ingested, it causes initial central nervous system stimulation, followed by depression. Later, it causes kidney damage which may terminate fatally.	(136, 177) -p.804
Ethyl Sulfide			Details unknown, but probably moderately toxic.	(177) -p.823
Fluoro Ethylenes			No specific physiological information available. Generally fluorinated compounds are potentially toxic because they yield fluorine, hydrofluoric acid, etc. after ingestion, which are toxic.	
Formaldehyde		5 0.1 for 90 days 0.1 for 1000 days	Toxic effects are mainly irritation. If swallowed it causes violent vomiting and diarrhea which can lead to collapse, increased airway resistance (animals) at threshold.	(136, 177) -p.844
Fluorotrichloromethane R-11		30,000 for 1 hr. 20,000 for 24 hrs. 1,000 for 90 days		(135, 136)

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Dichlorodifluoromethane		30,000 for 1 hr. 20,000 for 24 hrs. 1,000 for 90 days		(135, 136)
$F_2ClC\text{-}C\ ClF_2$ R-114		30,000 for 1 hr. 20,000 for 24 hrs. 1,000 for 90 days		(135, 136)
Freons		1000	High concentrations cause narcosis and anesthesia.	(177) -p.843
Hexachlorophene	Local:1		Strong concentrations may be irritating.	(177) -p.993
Hexamethylcyclotrisiloxane			No physiological information available. Generally siloxanes cause eye irritation.	
Hexamethylene Diamine	Acute Local:2		Local: irritant; ingestion, inhalation-all present.	(177) -p.874
N-Hexane		500	Local: irritant; ingestion, inhalation. Systemic: inhalation, ingestion.	(177) -p.875
Hexene-1	Acute Local:2 Acute Systemic: 2		Local: irritant; ingestion, inhalation. Systemic: inhalation	(177) -p.877
Hydrocyanic Acid		10	Can be absorbed via intact skin. A true protoplasmic poison, combining in the tissues with the enzymes associated with cellular oxidation and rendering the oxygen unavailable to the tissues.	(177) -p.883
Hydrogen	Acute Systemic:1	3,000 for 24 hrs. 3,000 for 90 days	Inhalation	(135, 136)
Hydrogen Chloride		10 for 1 hr. 4 for 24 hrs. 1 for 90 days	Irritating to the mucous membranes	(135, 136)
Hydrogen Fluoride		8 for 1 hr. 1 for 24 hrs. 0.1 for 90 days	Inhalation may cause ulcers of the upper respiratory tract. Produces severe skin burns, slow in healing.	(135, 136)
Hydrogen Sulfide		50 for 1 hr.	An irritant and an asphyxiant. The effect on the nervous system is one of depression with small amounts, stimulation with larger ones. Asphyxia is due to paralysis of the respiratory system.	(135, 136)

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Indole			No physiological information available. May be considered an emetic after long exposure.	
Isobutyl Alcohol	Acute Local:3 Acute Systemic: 2	100	Local: irritant; ingestion, inhalation. Systemic: ingestion, inhalation.	(177) -p.908
Isobutylene			Toxicity: details unknown. May have asphyxiant or narcotizing action.	(177) -p.909
Isoprene	Acute Local:2 Acute Systemic: 2		Concentrations of 5% are fatal.	(177) -p.913
Isopropyl Alcohol		400	Can cause corneal burns and eye damage. Acts as a local irritant and in high concentrations as a narcotic.	(177) -p.914
Lithium Hydroxide	Local:1 Systemic: 1-2		Large doses of lithium compounds have caused dizziness and prostration, particularly on a low sodium intake.	(177) -p.943
Maleic Acid	Acute Local:2		Irritant, ingestion, inhalation.	(177) -p.954
Manganese Oxide	Systemic: 2-3	5 mg per cubic meter of air	The central nervous system is the chief site of damage, usually after 1 to 3 years of exposure to heavy concentrations of dust or fumes.	(177) -p.956
Mercaptans	Acute Local:3 Systemic: 2-3	0.5	Local: irritant; inhalation Systemic: inhalation.	(177) -p.962
Mercury		0.1 mg per cubic meter of air	Chronic low grade exposure affects CNS and kidneys; may sensitize to oxygen toxicity and radiation.	(177) -p.971
Methane	Systemic: 1	5,000 for 24 hrs. 5,000 for 90 days	Inhalation	(135, 136)
Methyl Acrylate		10	Chronic exposure has produced injury to lungs, liver and kidneys in experimental animals.	(177) -p.980

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per 25M^3	Comments	References
Methyl Alcohol		200 for 24 hrs. 10 for 90 days	Distinct narcotic properties. Slight irritant to the mucous membranes. Main toxic effect is on the nervous system, particularly the optic nerves. Once absorbed, it is only very slowly eliminated; coma may last 2-4 days. A cumulative poison.	(135, 136)
2-Methylbutanone		20 for 90 days 20 for 1000 days	Irritation of mucous membranes in man at threshold.	(136)
Methyl Chloride		100	Repeated exposure to low concentrations causes damage to the CNS, and less frequently to the liver, kidneys, bone marrow and cardiovascular system. Exposure to high concentrations may result in delirium, coma and death.	(177) -p. 987
Methyl Chloroform		1,000 for 1 hr. 500 for 24 hrs. 200 for 90 days	Local: irritant by ingestion, inhalation Systemic: toxic by ingestion, inhalation	(135, 136)
Methylene Chloride		500	Very dangerous to the eyes. Strong narcotic powers.	(177) -p. 993
Methylethyl Ketone		200	Local irritation and narcosis.	(177) -p. 534
Methyl Isopropyl Ketone		200	No physiological information available. In general it should have same irritant properties as low molecular weight ketones; i.e., eye, skin and respiratory tract irritant.	
Methyl Methacrylate	Acute Local:1 Systemic: 1		Local: irritant by ingestion, inhalation. Systemic: toxic by ingestion, inhalation.	(177) -p. 1000
Methyl Nitrate	Systemic:2		Ingestion, inhalation	(41)
3-Methyl-Pentane			Details unknown; may have narcotic or anesthetic properties.	(177) -p. 1002
Methyl Salicylate	Local:1-2 Acute Systemic:3		Acute accident poisoning is not uncommon. Kidney irritation, vomiting and convulsions occur.	(177) -p. 1005

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per 25M^3	Comments	References
Monoethanolamine		50 for 1 hr. 3 for 24 hrs. 0.5 for 90 days	A skin irritant and necrotizer; a central nervous system stimulant in low doses; a depressant at high doses.	(135, 136)
Monomethylhydrazine		0.2	A respiratory irritant and convulsant at low doses.	(136, 223, 224)
Nitric Oxide		5	60-150-ppm-immediate irritation of throat and nose. Shortness of breath, restless, loss of consciousness and - death may follow. 100-150 ppm for 30-60 minutes is dangerous.	(177)
Nitrogen Dioxide		10 for 1 hr. 1 for 24 hrs. 0.5 for 90 days	Highly toxic.	(135, 136)
Nitrous Oxide	Acute Systemic: 2		Inhalation	(177) -p.1052
Olefins			Prolonged exposure to high concentrations has led to liver damage and hyperplasia of the marrow in animals; no corresponding effects have been found in humans. Relatively innocuous.	(177) -p.1060
Ozone		1.0 for 1 hr. 0.1 for 24 hrs. 0.02 for 90 days	Strong irritant action on the upper respiratory system.	(135, 136)
N-Pentane	Acute Systemic: 1		Inhalation. Narcotic in high concentrations.	(177) -p.1074
Phenol		5	Can be absorbed through intact skin. Main effect is on the CNS in acute poisoning. Death may result within 30 minutes to several hours of spilling on the skin.	(177) -p.1083
Phosgene		1.0 for 1 hr. 0.1 for 24 hrs. 0.05 for 90 days	Irritating to eyes and throat. The main fatal effect is pulmonary edema.	(135, 136)
Potassium Dichromate		0.1	A corrosive action on the skin and mucous membranes. Characteristic lesion is a deep ulcer, slow in healing. Chromate salts have been associated with cancer of the lungs.	(177) -p.1118

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
Propane	Acute Systemic: 1	1000	Inhalation	(177) -p.1134
N-Propylacetate		200	Causes narcosis and is somewhat irritating. Definite evidence of habituation - not likely to cause chronic poisoning.	(177) -p.1137
Propylene	Acute Systemic: 2		Inhalation. A simple asphyxiant.	(177) -p.1139
Silicic Acid			Toxicity slight, but dangerous in weightless conditions as it may form powders if not well confined.	(177) -p.1171
Skatole			No specific physiological information available. May be considered an emetic after lengthy exposures.	
Sulfur Dioxide		10 for 1 hr. 5.0 for 24 hrs. 1.0 for 90 days	Irritating to nose and throat. MAC for 30-60 minutes exposure is 50-100 ppm. 400-500 ppm immediately dangerous to life.	(135, 136)
Terepthalic Acid			No specific physiological information available. A mild irritant with low acute oral toxicity.	(177)
Tetrachloroethylene		100	Toxic by inhalation, prolonged or repeated contact with the skin, or mucous membranes or when ingested. Liquid can cause injuries to the eyes, irritation of the nose and throat.	(177) -p.1077
Tetrafluoroethylene Inhibited			Toxicity: can act as an asphyxiant and may have other toxic properties.	(177) -p.1230
Toluene		100 for 24 hrs.	Impairment of coordination and reaction time. Few cases of acute toluene poisoning.	(135, 136)
Toluene 2,4 di-isocyanate		0.02	Severe dermatitis and bronchial spasm. Particularly irritating to the eyes.	(136) -p.1259
Tri-aryl phosphates		5.0	As cresol. Ingestion, inhalation skin absorption.	(41)

Table 13-15 (continued)

Agent	Toxic Code	Recommended Limits* ppm or mM per $25M^3$	Comments	References
1,1,1-Trichloroethane		1,000 for 1 hr. 500 for 24 hrs. 200 for 90 days	Narcotic at low levels. High levels may affect liver and lungs.	(135, 136)
Trichloroethylene		100 10 for 90 days 2 for 1000 days	Inhalation of high concentrations causes narcosis and anesthesia. A form of addiction has been observed. Death from cardiac failure due to ventricular fibrillation has been reported.	(135, 177) -p.1269
1,1,2-Trichloro, 1,2,2-Trifluoroethane (Freon 113) and congeners		30,000 for 60 min. 1,000 for 90 days 200 for 1000 days	CNS and cardiovascular effects at threshold in animals.	(136)
1,1,3-Trimethylcyclohexane			No physiological information available. Suspect it should be a skin irritant (solvent action) and irritant of the respiratory tract.	
Urea			Toxicity: no importance as an industrial hazard. Slightly dangerous when heated.	(177) -p.1314
Valeric Acid			Toxicity: details unknown. Nauseating. See Butyric Acid.	(177) -p.1315
Vinyl Acetate	Local:1 Acute Systemic: 1		Local: Irritant Systemic: Inhalation.	(177) -p.1319
Vinyl Chloride		500	In high concentrations it acts as an anesthetic. Causes skin burns by rapid evaporation and consequent freezing.	(177) -p.1321
Vinylidene Chloride		5 for 30 to 90 days	Details unknown. See Vinyl Chloride.	(136)
Xylene		100 for 24 hrs.	Local: irritant. Systemic: inhalation, skin absorption.	(136)

recommended limit is the TLV (Earth equivalent) which covers exposures for 8 hrs./day, 5 days per week at standard temperatures and pressures. Some of the provisional limits for other exposure periods are those recommended by the NAS/NRC. The rationale behind these provisional limits for specific compounds is presented in detail in Reference (136) and general philosophy behind the approach is discussed on pages 13-1 through 13-4.

In brief, the provisional long-term limits recommended were chosen with the objective of avoiding: adverse health effects, either immediate or delayed; degradation of performance; and interference with physiological studies on crew members. The provisional 60-minute emergency limits are designed to avoid significant degradation in crew performance in emergencies and to avoid permanent health injury. They contain essentially no safety factor, and transitory effects may result. Because of the inadequacies of the data mentioned above, particularly the fact that most current toxicologic data are based on non-continuous exposure, and because of uncertainty as to synergism among chemicals, and to allow for the possibility of minor excursions above the ceiling limit, a safety factor has been applied to each 90 and 1000-day limit value. The magnitude of the safety factor differs according to the toxicologic category of the contaminant. If the contaminant is an irritant at the threshold of response, an estimated factor of 5 is included in the limit. If the contaminan is capable of producing systemic, irreversible injury, a factor of 20 is included.

The duration of exposure to which a limit value applies is determined by the type of response induced by a given contaminant. If a local irritant (e.g., the butanones), the Committee felt that so long as the concentration was kept below the irritant level no cumulative effects would occur. In such cases, the 90-day limit applies equally to a 1000-day mission. When, however, the contaminant has the potential for cumulative action, albeit at an exposure level well above the provisional limit for 90 days, a reduction appropriate to the seriousness of the response is made for the 1000-day mission. In such instances, a five-fold reduction in the 90-day limit has been arbitrarily made (e.g., chloroform, dioxane). The other non-TLV limits are those previously recommended for nuclear submarine exposures by the NAS-NRC Committee on Toxicology (135) and accepted as valid for space cabins (136). The toxic hazard rating represents a classification by severity as noted in code at top of table.

Table 13-16 presents a summary of the agents found during different tests and of previous attempts to set limits for exposures other than those for TLV. The references for each column are noted in parentheses after the title. These data of Table 13-16 are presented as historical guides. The limits of Table 13-15 are those currently recommended.

Classification of these and other possible toxic contaminants is available (41, 86). The data are organized alphabetically as well as in chemical classes and sites of action. The chemical classification is noted in Table 13-17 (86) and the toxic effects in body systems, noted in Table 13-18. Tables 13-17 and 13-18 represent check lists of compounds already found in sealed environments as well as some that are suspected as future contaminants.

Table 13-16

Contaminants Found in Sealed Cabins and Their Compartments and Past Attempts at Setting Atmospheric Limits

(After NAS-NRC(136))

COMPOUND	MOL. WT.	REPORTED OCCURRENCES																		ATMOSPHERIC LIMITS							
		Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Mesa I (40)(175)	Mesa II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)		ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135) 1 Hour	SUBMARINE (135) 24 Hour	SUBMARINE (135) 90 Day	Boeing Company (86)	DOUGLAS (42) Continuous'	DOUGLAS (42) Alert	DOUGLAS (42) Abort
Acetaldehyde	44.05	X	X						X	X	X	X	X	X	X	X	X			200	3				50	5	20	200
Acetic Acid	60.05						X		X	X					X	X	X			10	2				2	4	1 6	10
Acetone	58.08	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			1000	[a] 85		2000	300	50	20	80	1000
Acetylene	26.04	X	X	X											X		X						2500	2500	2500	25,000		
Allene	40.07								X															[b]				
Allyl Alcohol	58.08								X	X	X									2								
Ammonia	17.03			X			X			X		X				X	X			50	30	400	50	25	25	25	100	100
Amyl Acetate	130.18									X	X									100	[a] 20				20			53
Amyl Alcohol	88.15									X											25				25			50
Acrylonitrile	53.06							X												20						0.4	1.6	20
Benzene	78.11	X		X	X		X		X	X	X			X	X	X	X			25	[a] 6		100	1	5			
Benzyl Ether	198.25								X	X																		
1-3 Butadiene	54.09				X		X		X											1000	45			[b]				
n-Butane	58.12	X	X	X	X		X		X			X	X		X		X							[b]	5000			
iso-Butane	58.12								X								X											
*2-Butanone	72.06	X	X				X		X	X	X	X		X		X	X			200	70				100	4	16	200

* = Listed under two synonyms

a = USSR Community Levels available

b = Submarine Levels

Aliphatic Hydrocarbons	60 mg/m3
Aromatic Hydrocarbons (other than benzene)	10 mg/m3
Benzene	3 mg/m3

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Mesa I (40)(175)	Mesa II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Orygossing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV's (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
1-Butene	56.10	X		X			X		X						X		X						b	4000			
2-Butene cistrans	56.10	X	X				X		X						X		X						b	4000			
Butyl Acetate	150.61								X		X								150	a 40				50			
iso-Butyl Acetate	150.61								X		X				X	X	X		100	65				25			
n-Butyl Alcohol	74.12	X	X						X		X				X	X	X							25			
iso-Butyl Alcohol	74.12		X				X		X	X	X				X												
sec-Butyl Acrylate	128.17						X																b				
n-Butyl Benzene	134.21																X						b				
tert-Butyl Benzene	134.21									X							X						b				
iso-Butylene	56.10								X			X			X		X							100			
Butyraldehyde	72.10								X	X	X																
-Butyrolactone	86.09																X							5			
Butyric Acid	88.10																	X									
Carbon Dioxide	44.01	X							X	X	X	X	X	X	X	X	X		5000		25,000	10,000	5000	5000	10,000	12,500	15,000
Carbon Disulfide	76.14		X		X					X						X			20					2			
Carbon Monoxide	28.01			X		X				X	X					X	X		50	65	17	200	25	25	25	100	100

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
Carbon Tetrachloride	153.82						X		X	X	X								10	3				2	.5	2	10
Carbonyl Sulfide	60.07											X				X											
Chlorine	70.91																X		1			1	0.1	.5	0.4	.16	1.0
Chlorobenzene	112.56								X	X	X								75	11							
1-Chlorobutane	92.57							X																			
Chlorofluoro Bromomethane	147.47							X																			
Chlorofluoro ethylene	80.5			X				X																			
Chloroform	119.38			X			X		X	X	X					X			50								
Chloromethane	50.49			X				X	X			X							100					200	2	8	100
Chloropropane	78.54		X																								
Cyclohexane	84.16		X	X	X		X	X	X	X	X							X	300				b	200			
Cyclohexene	82.14								X		X								300				b				
Cyclopentane	70.13			X	X				X	X													b				
Cyclopentene	68.11										X												b				
Cyclopropane	42.08								X														b				
Decalin (various isomers	138.25								X	X	X																

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES																										ATMOSPHERIC LIMITS								
		Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135) 1 Hour	SUBMARINE (135) 24 Hour	SUBMARINE (135) 90 Day	Boeing Company (86)	DOUGLAS (42) Continuous	DOUGLAS (42) Alert	DOUGLAS (42) Abort
Decane	142.29									X																								
Dichloroacetylene	94.93											X																						
Dichlorobenzene	147.01															X			75	3														
1-2, Dichloroethane	98.96	X					X		X	X	X			X					50	2.5				5										
Dichloroethene	96.95		X																															
1-1, Dichloroethylene	98.96	X					X	X	X	X		X																						
1-2, Dichloroethylene	98.96				X																													
*Dichloromethane	84.93	X	X			X	X	X	X	X	X			X	X				500	14				100										
1-2, Dichloropropane	112.99							X											75															
1-3, Dichloropropane	12.99							X																										
Diethylbenzene	34.21									X													b											
1-4, Dimethoxy benzene	38.16								X																									
Dimethylamine	45.08									X									10					5										
2-2, Dimethylbutane	86.17	X	X	X			X			X	X												b	4000										
2-3, Dimethylbutane	86.17									X	X												b											
Dimethylcyclohexane	12.22									X	X												b											

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
Dimethylcyclopentane	100.13								X	X													[b]				
1-3, Dimethyl-5 ethylbenzene	134.22															X							[b]	25			
Dimethyl Furan	96.13								X	X	X																
Dimethyl Naphthalene	156.22								X	X													[b]				
2,4-Dimethyl Pentane	100.21									X													[b]				
Dimethyl Propane	72.15									X													[b]				
Dimethyl Sulfide	62.14									X	X													5	4	16	20
Dimethyl Thiophene	112.19								X																		
1,4-Dioxane	88.11	X					X							X					100	3				10			
Dioxene	86.10	X	X	X	X																			10			
Ethane	30.07		X	X	X	X	X	X	X	X							X						[b]				
Ethanethiol	62.13	X			X	X	X	X		X									10					2			
2-Ethoxyethanol	90.12															X			200								
2-Ethoxyethyl Acetate	132.16															X			100								
Ethyl Acetate	88.10	X	X	X		X		X	X	X				X	X	X	X		400	[a] 55				50			
Ethyl Acetylene	54.09		X																								

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
Ethyl Acrylate	100.12							X											25								
Ethyl Alcohol	46.07	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		1000	530		500	100	200			
Ethylamine	45.08															X			10					1			
Ethyl benzene	106.16								X	X	X					X	X	X	100				b	20			
Ethyl Chloride	64.52											X							1000								
Ethyl Cyclohexane	112.22																X										
Ethylene	28.05	X	X				X		X	X	X			X	X		X						b	500			
Ethylene Oxide	44.05															X			50	316							
Ethyl Ether	74.12			X	X				X	X	X	X	X						400	100				100			
Ethyl Formate	74.08								X	X	X				X				100					20			
*p-Ethyl Toluene	120.19									X						X	X						b	20			
Formaldehyde	30.03	X	X												X	X	X		5	0.8				0.1	0.2	0.8	5
Fluoroethane	48.06							X																			
2-Fluoropropene	60.07							X																			
R-11. Fluorotrichloro-methane	137.38	X	X	X			X			X	X			X			X		1000		30,000	20,000	1000	500			
R-12 Dichlorodifluoromethane	121.00	X					X			X									1000		30,000	20,000	1000	500			

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
R-22, Chlorodifluoromethane	86.50	X	X	X					X	X	X													500			
R-23, Trifluoromethane	70.01	X	X																					500			
R-113, FCl_2C-$CClF_2$	187.39						X		X		X								1000					500			
R-114, F_2ClC-$CClF_2$	170.93	X	X					X	X	X	X			X			X		1000					500			
*R-125, F_2HC-CF_3	121.03	X	X					X		X										30,000	20,000	1000		500			
Furan	68.07				X			X	X	X									1000					500			
Furfural	96.08								X										5					10			
Furfuryl Alcohol	98.10								X										50								
n-Heptane	100.20						X		X	X	X				X	X	X		500				b	200			
Heptene	98.18								X														b				
Hexafluorobenzene	186.00								X																		
Hexamethyl cylotrisiloxane	166.00	X																									
n-Hexane	86.17	X	X	X				X	X	X	X				X	X	X		500				b	50			
Henxene	84.16	X							X														b	200			
Hexene-1	84.16		X																				b				
Hydrogen	1.01		X						X						X		X				3000	3000	3000	1			
																									3000	3000	30,000

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Mesa I (40)(175)	Mesa II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV's (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
Hydrogen Chloride	36.46																X		5		10	4	1	0.1	0.1	0.4	5
Hydrogen Fluoride	20.01								X								X		3		8	1	0.1	0.1	0.1	0.4	3
Hydrogen Sulfide	34.08			X					X								X		10	7[a]	50			2	4	16	20
Indene	116.15						X		X	X																	
Indole	117.14									X														0.5			
Isoprene	68.11						X		X	X	X				X				200					200			
Isopentane	72.15	X	X						X	X	X	X					X						b	1,000			
* Mesitylene	120.19								X	X							X						b				
Methane	16.04		X	X	X		X	X	X	X						X	X	X	5,000		5,000	5,000	5,000	2,500			
Methyl Acetate	74.08									X	X								200	[a] 35				25			
Methyl Alcohol	32.04	X	X	X	X		X		X	X	X	X	X	X				X	200	[a] 40		200	10	3	4	16	200
Methylamine	31.06								X										10					1			
2-Methylbutanone-3	86.13	X								X			X														
Methyl Chloride	50.49			X				X	X			X							100					200	2	8	100
Methyl Chloroform	133.42	X							X	X	X			X			X		350		1000	500	200	50			
Methyl Cyclohexene	96.17									X													b				

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV's (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
Methyl Cyclopentane	84.13										X							X					[b]				
* Methylene Chloride	84.89	X	X		X	X	X	X	X	X	X	X			X	X			500	14				100			
Methyl Cyclohexane									X	X	X						X	X	500				[b]				
Methylethyl benzene	120.19									X						X	X						[b]	20			
Methyl Ethyl Ketone	72.06	X	X				X		X	X	X	X		X	X	X	X		200	70				100	4	16	200
Methyl Ethyl Thiophene	126.18								X																		
Methyl Formate	60.05												X						100					10			
Methyl Furan	82.10								X	X	X									0.3				10			
Methyl iso Butyl Ketone	100.16								X	X	X				X	X			100					10			
Methyl iso Propyl Ketone	86.13	X									X			X										2	1	4	50
Methanethiol	48.10					X			X	X									10								
Methyl Methacrylate	100.11										X				X				100					10			
Methyl Naphthalene	142.19								X	X													[b]				
Methyl Butyrate	102.13								X	X	X																
2-Methyl Pentane	86.17	X									X												[b]				
3-Methyl Pentane	86.17	X	X																1000								

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
4-Methyl-2 Pentanone	100.16						X																				
Methylsiloxane Polymers									X	X							X	X									
Methyl Thiophene	84.14						X		X																		
Monochloro Acetylene	60.48											X															
Monoethanolamine	75.11																X		3		50	3	0.5	1			
Napthalene	128.16								X	X	X								10								
Nitric Oxide	30.01							X									X						1		0.4	1.6	10
Nitrogen Dioxide	32.01												X				X		5		10	1	0.5	.5	0.2	0.8	5
Nitrous Oxide	44.01																X							5000			
n-Nonane	128.25																	X						b			
Octane	114.23									X							X		500					b			
* iso-Octane	114.23								X	X									200					b			
Ozone	48.00																X		0.1		1.0	0.1	0.02	0.05	0.004	0.016	0.1
Pentafluoroethane	121.03		X	X					X		X								1,000					500			
Pentane	72.15		X	X						X	X	X					X							1,000			
iso-Pentane	72.15		X	X						X	X	X					X							1,000			

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
1-Pentene	70.13								X			X											[b]				
Perchloroethylene	165.85		X						X	X	X				X				100								
Phenol	94.11															X			5	1.3				1.0	0.2	0.8	5.0
Phosgene	98.92											X							0.1		1.0	0.1	0.05	0.05	0.04	0.16	1.0
Propane	44.09	X		X	X		X	X	X	X							X		1,000				[b]	1000		1800	
Propene	42.08					X		X															[b]				
Propenenitrile	53.06							X											20						0.4	1.6	20
Propionaldehyde	58.08														X									50			
Propionic Acid	74.08								X	X				X			X							2			
Propyl Acetate	102.13								X	X	X								200	50							
n-Propyl Alcohol	60.09	X	X						X	X	X			X		X			200	80				100			
iso-Propyl Alcohol	60.09			X	X	X	X		X	X	X					X	X		400	80				100			
iso-Propyl Benzene	120.19															X			50					20			
n-Propyl Benzene	120.19								X								X						[b]				
* Propyl Chloride	78.54	X								X	X																
Propylene	42.08	X	X						X	X	X				X		X						[b]	1000			

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
iso-Propyl Ether	102.17								X	X	X								500								
Propanethiol	76.16								X	X	X																
iso-Propanethiol	76.16						X																				
Propyne	40.06								X										1000				b	1000			
Pseudocumene	120.19								X	X							X						b	20			
Silicone Oil																X											
Skatole	131.17								X															0.5			
Styrene	104.14								X	X									100	a 12			b				
Sulfur Dioxide	64.06		X									X					X		5		10	50	1.0	0.2	0.2	0.8	5
1, 2, 4, 5-Tetrachlorobenzene	215.90															X											
Tetrachloroethane	102.03									X																	
Tetrafluorobenzene	150.00									X																	
Tetrafluoroethylene	100.2		X																								
Tetrahydrofuran	72.10								X	X	X								200					20			
Tetramethylbenzene	134.21								X	X																	
Toluene	92.13	X	X	X	X		X		X	X	X			X	X	X	X	X	200	13		100	b	50			

Table 13-16 (continued)

COMPOUND	MOL. WT.	REPORTED OCCURRENCES: Mercury (169)(172)	GT-3 (78)	GT-4 (78)	GT-5 (78)	GT-7 (78)	GT-10 (78)	GT-12 (78)	SAM I (36)	SAM II (35)	SAM III (1)	Meso I (40)(175)	Meso II (40)	Merc. Malfunction (169)	Integrated L/S/S (87)(208)	Offgassing (78)(90)(100)	Submarines (14)	Sea Lab II (78)(176)	ATMOSPHERIC LIMITS: ACGIH TLV'S (6)	USSR Industrial (213)	SUBMARINE (135): 1 Hour	24 Hour	90 Day	Boeing Company (86)	DOUGLAS (42): Continuous	Alert	Abort
*1, 1, 1-Trichloroethane	133.42	X							X	X	X			X			X		350		1000	500	200	50			
Trichloroethylene	131.40	X	X						X	X	X			X	X	X			100	9				20			
Trifluorobenzene	132.00									X																	
Trifluorochloroethane	104.5							X																			
*1, 3, 5-Trimethyl Benzene	120.19								X	X							X						b				
Trimethyl Hexane	128.24									X													b				
*Trimethyl Pentane	114.22			X					X	X									200				b				
Trimethylsilanol	80.00															X											
Valeric Acid	102.13								X	X																	
Vinyl Chloride	62.50	X	X						X		X			X			X		500	12				100	10		
Xylene	106.16	X					X		X	X	X			X		X	X	X	100	12		100	b	50	40		500
m-Xylene	106.16	X																									

Table 13-17

Chemical Classification of Contaminants Already Found or Predicted in Space Cabins

(After Hine and Weir[86])

ACIDS, INORGANIC (2)
- Hydrogen fluoride
- Sulfuric acid

ACIDS, ORGANIC (8)
- Acetic acid
- Butyric acid
- Formic acid
- Hippuric acid
- Lactic acid
- Oxalic acid
- Propionic acid
- Pyruvic acid

ALCOHOLS (11)
- Allantoin
- iso-Amyl alcohol
- Benzyl alcohol
- n-Butyl alcohol
- iso-Butyl alcohol
- sec.-Butyl alcohol
- tert.-Butyl alcohol
- Ethanol
- Methanol
- n-Propyl alcohol
- iso-Propyl alcohol

ALDEHYDES (7)
- Acetaldehyde
- Acrolein (unsaturated aliphatic ald.)
- n-Butyraldehyde
- Formaldehyde
- Propionaldehyde
- n-Valeraldehyde
- iso-Valeraldehyde

ALIPHIC HYDROCARBONS (9)
- n-Butane
- Dimethylbutane
- n-Heptane
- n-Hexane
- Methane
- 3-Methylpentane
- n-Pentane
- iso-Pentane
- Propane

AMIDES (2)
- Formamide
- Urea

AMINES (7)
- Dimethylamine
- Ethylamine
- Ethylamine diamine
- Histamine
- Methylamine
- Monoethanolamine
- Trimethylamine

AROMATIC HYDROCARBONS (13)
- Benzene
- Cumene
- 1, 3-Dimethyl-5-Ethylbenzene
- Ethylbenzene
- p-Ethyl toluene
- Pseudocumene
- Resorcinol
- Toluene
- Cyclohexane
- 1, 3, 5, -Trimethylbenzene
- m-Xylene
- o-Xylene
- p-Xylene

ESTERS (8)
- n-Amyl acetate
- n-Butyl acetate
- Ethyl acetate
- Ethyl formate
- Methyl acetate
- Methyl formate
- Methyl methacrylate
- Triaryl phosphate

ETHERS (5)
- 1, 4-Dioxane
- Ethyl ether
- Furan
- Methyl furan
- Tetrahydrofuran

GLYCOLS (1)
- Ethylene glycol

HALOGENATED HYDROCARBONS (16)
- Carbon tetrachloride
- Ethylene dichloride
- Freon-11
- Freon-12
- Freon-22
- Freon-23
- Freon-113
- Freon-114 sym
- Freon-114 uns
- Freon-125
- Methyl bromide
- Methyl chloride
- Methyl chloroform
- Trichloroethylene
- Vinyl chloride
- Vinylidene chloride

HYDRAZINES (3)
- Hydrazine
- uns-Dimethyl hydrazine
- Monomethyl hydrazine

Table 13-17 (continued)

INDOLES (4)
- Indican
- Indole
- Skatole
- Skatoxyl Sulfuric acid

INORGANIC GASES (7)
- Chlorine
- Hydrogen
- Hydrogen chloride
- Nitrogen
- Oxygen
- Ozone
- Radon

INORGANIC HYDRIDES (7)
- Ammonia
- Arsine
- Decaborane
- Pentaborane-9
- Phosphene
- Stibine
- Water and Water Vapor

KETONES (5)
- Acetone
- Chloroacetone
- Cyclopentanone
- Methyl ethyl ketone
- Methyl isobutyl ketone

METALS AND THEIR OXIDES (22)
- Aluminum
- Antimony
- Beryllium
- Cadmium
- Calcium
- Chromium
- Copper
- Gold (metal only)
- Iron
- Lead
- Magnesium
- Manganese
- Mercury
- Molybdenum
- Nickel
- Potassium
- Tellurium
- Selenium
- Silver
- Sodium
- Titanium
- Zinc

MISCELLANEOUS (2)
- Cigarette smoke
- Gasoline

NITRILES (3)
- Acetonitriles
- Hydrogen cyanide
- Methyl isocyanide

NITROGENOUS BASES (2)
- Creatinine
- Uric acid

OXIDES, INORGANIC (4)
- Nitric oxide
- Nitrogen dioxide
- Nitrous oxide
- Sulfur dioxide

OXIDES, ORGANIC (6)
- Carbon dioxide
- Carbon Monoxide
- Nitrogen oxychloride
- Phosgene
- Sulfuryl chloride
- Thionyl chloride

PHENOLS (2)
- p-Cresol
- Phenol

SILICON COMPOUNDS (1)
- Hexamethylcyclotrisiloxane

SULFIDES (6)
- Carbon disulfide
- Carbonyl sulfide
- Dimethyl sulfide
- Ethyl sulfide
- Hydrogen sulfide
- Methyl sulfide

SULFUR COMPOUNDS (2)
- Ethyl mercaptan
- Methyl mercaptan

UNSATURATED ALIPHATIC HYDROCARBONS (9)
- Acetylene
- Butene-1
- cis-Butene-2
- trans-Butene-2
- Ethylene
- Hexene-1
- Isoprene
- Methyl acetylene
- Propylene

Table 13-18

Classification of Possible Contaminants of the Space Capsule According to Their Toxic Effects on Different Body Systems (After Hine and Weir[86])

	Autonomic N.S.	Blood	Cardiovascular	CNS Depressant	CNS Stimulant	Enzyme Inhibitor	Hemopoetic Tissue	Hepato Agent	Mucous Membrane	Nephro Agent	Peripheral N.S.	Respiratory	Simple Asphyxiant
	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Acetaldehyde				*								*	
2. Acetic acid									*			*	
3. Acetone				*					*				
4. Acetonitrile					*	*						*	
5. Acetylene				*					*				*
6. Acrolein									*	*		*	
7. Allantoin													
8. Aluminum												*	
9. Ammonia					*				*			*	
10. iso-Amyl alcohol			*	*					*			*	
11. n-Amyl acetate				*					*			*	
12. Antimony			*					*		*		*	
13. Arsine		*						*	*	*		*	
14. Benzene			*	*			*		*			*	
15. Benzyl alcohol				*									
16. Beryllium						*			*	*		*	
17. n-Butane				*									*
18. Butene-1				*									*
19. cis-Butene-2				*									*

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
20. trans-Butene-2				*									*
21. n-Butyl acetate				*					*			*	
22. n-Butyl alcohol				*				*	*	*		*	
23. iso-Butyl alcohol				*					*			*	
24. sec-Butyl alcohol				*					*			*	
25. tert-Butyl alcohol				*					*				
26. n-Butyraldehyde									*			*	
27. Butyric acid									*				
28. Cadmium										*		*	
29. Calcium									*			*	
30. Carbon dioxide				*									*
31. Carbon disulfide					*	*					*		
32. Carbon monoxide		*											
33. Carbon tetrachloride			*	*				*		*			
34. Carbonyl sulfide					*	*							
35. Chlorine									*			*	
36. Chloroacetone									*			*	
37. Chromium									*	*		*	
38. Cigarette smoke(?)													
39. Copper									*			*	
40. Creatinine				*									
41. p-Cresol					*				*	*		*	
42. Cumene				*				*	*			*	
43. Cyclohexane				*				*		*			
44. Cyclopentanone				*									
45. Decaborane				*									

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
46. Dimethylamine												*	
47. Dimethylbutane				*									
48. 1-3-Dimethyl-5-ethylbenzene													
49. uns-Dimethyl hydrazine(UDMH)					*								
50. Dimethyl sulfide						*							
51. 1,4 Dioxane				*				*	*	*		*	
52. Dioxene				*					*				
53. Ethanol				*					*				
54. Ethyl acetate				*					*			*	
55. Ethylamine			*						*				
56. Ethyl benzene				*					*			*	
57. Ethylene				*									
58. Ethylene diamine								*	*	*		*	
59. Ethylene dichloride				*				*		*		*	
60. Ethylene glycol										*		*	
61. Ethyl ether				*					*				
62. Ethyl formate				*					*			*	
63. Ethyl mercaptan				*									
64. Ethyl sulfide						*			*				
65. p-Ethyl toluene				*					*			*	
66. Formaldehyde									*			*	
67. Formamide									*				
68. Formic acid									*				
69. Freon 11				*					*				*
70. Freon 12				*					*				*

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
71. Freon 22				*					*				*
72. Freon 23				*					*				*
73. Freon 113				*					*				*
74. Freon 114-sym													
75. Freon 114-unsym													
76. Freon 125													
77. Furan				*					*				
78. Gasoline vapors				*					*				
79. Gold								*		*			
80. n-Heptane				*					*				
81. Hexamethylcyclo-trisiloxane									*			*	
82. n-Hexane									*			*	*
83. Hexene-1				*					*				
84. Hippuric acid									*				
85. Histamine	*		*										
86. Hydrazine					*			*		*			
87. Hydrogen													*
88. Hydrogen chloride									*			*	
89. Hydrogen cyanide					*	*							
90. Hydrogen fluoride						*		*	*	*		*	
91. Hydrogen sulfide						*			*			*	
92. Indican									*				
93. Indole		*							*				
94. Iron												*	
95. Isoprene				*					*				
96. Lactic acid									*				

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
97. Lead					*								
98. Magnesium				*					*				
99. Manganese				*				*				*	
100. Mercury			*		*			*		*			
101. Methane				*									*
102. Methanol				*		*					*		
103. Methyl acetate				*								*	
104. Methyl acetylene				*								*	
105. Methyl amine												*	
106. Methyl bromide				*				*				*	
107. Methyl chloride									*			*	
108. Methylene chloride				*					*				
109. Methylchloroform			*	*				*	*				
110. Methyl ethyl ketone				*					*			*	
111. Methyl formate				*					*			*	
112. Methyl furan				*					*			*	
113. Methyl cyanide						*							
114. Methyl isobutyl ketone				*								*	
115. Methyl mercaptan						*						*	
116. Methyl methacrylate				*					*				
117. 3-Methylpentane				*					*				
118. Methyl sulfide												*	
119. Molybedenum									*			*	
120. Monothanolamine								*	*	*		*	
121. Nickel									*			*	
122. Nitric oxide				*					*			*	

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
123. Nitrogen													*
124. Nitrogen dioxide									*			*	
125. Nitrogen oxychloride									*			*	
126. Nitrous oxide				*									*
127. Oxalic acid									*	*			
128. Oxygen						*						*	
129. Ozone						*			*			*	
130. Pentaborane-9					*								
131. n-Pentane				*									
132. iso-Pentane				*									
133. Phenol		*	*					*		*			
134. Phosgene												*	
135. Phosphene								*		*		*	
136. Potassium									*			*	
137. Propane				*									*
138. Propionaldehyde				*					*				
139. Propionic acid									*			*	
140. n-Propyl alcohol				*					*				
141. iso-Propyl alcohol				*					*				
142. Propylene				*									*
143. Pseudocumene				*					*				
144. Pyruvic acid									*			*	
145. Radon		*					*						
146. Resorcinol									*			*	
147. Selenium								*		*			

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
148. Silver												*	
149. Skatole												*	
150. Skatoxylsulfuric acid												*	
151. Sodium									*			*	
152. Stibine		*				*						*	
153. Sulfur dioxide									*			*	
154. Sulfuric acid									*			*	
155. Sulfuryl chloride									*			*	
156. Tellurium						*		*					
157. Tetrahydrofuran				*				*	*	*		*	
158. Thionylchloride									*			*	
159. Titanium		*										*	
160. Toluene				*				*	*	*			
161. Triaryl phosphate											*		
162. Trichloroethylene								*	*	*		*	
163. Trimethylamine									*			*	
164. 1,3,5-Trimethylbenzene				*				*	*				
165. Urea													
166. Uric acid													
167. n-Valeraldehyde									*			*	
168. iso-Valeraldehyde									*			*	
169. Vinyl chloride				*				*					
170. Vinylidene chloride				*					*				
171. Water and water vapor													

Table 13-18 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
172. m-Xylene								*	*			*	
173. o-Xylene								*	*			*	
174. p-Xylene								*	*			*	
175. Zinc									*				

A more detailed outline of toxic response is given for each compound under "comments" in Table 13-15 or in the references of this table.

The recommendation for "alert levels" and "abort" and TLV_{space} in the classifications of References (42) and (86) must still be looked on with some skepticism because of the complexity of variables covered above. The rationale in Reference (86) is well documented and is a good source for basic data. These data represent the first attempt at the extrapolation for many compounds and should be strictly viewed as such. Papers on Soviet toxic hazard standards are available for comparison of general approaches to industrial values (56, 168, 213).

The reproducibility of the levels of toxic materials found in space cabin simulators has been recorded (36). Detailed analyses of these materials illustrate the variability of data from sample to sample and laboratory to laboratory. At the present state of the analytic and sampling art, any data on "the highest concentration" found in sealed cabins must be viewed with the appropriate level of skepticism suggested by these data.

Malfunctions and Emergencies

In addition to materials present during normal operations, one must consider the toxic atmospheres resulting from fire or equipment failure. Some of these may be subtle and never anticipated (174, 175). (See also page 13-82.)

Gaseous products from burning of plastics and other materials have been noted as have the toxic products of fire extinguishers and the extinguishing process (80, 101, 162, 164). One must consider not only the products of overt fires but those from thermal decomposition due to overheating of equipment. Toxic atmospheres result from thermal decomposition of electrical equipment, hydraulic fluid, and oil. Low temperature greases volatilize and electrical insulation may charr. On occasion, selenium rectifiers have given problems in aircraft. Pyrolyses of hydraulic fluids including the silicones, fluorohydrocarbons, and phosphate esters have given off materials which are irritating to the eye and respiratory tract. Carbon monoxides and aldehydes are frequent breakdown products in equipment failure.

Freon decomposition products form on contact of this class of compounds with hot surfaces. These may include hydrogen halides. The toxicity of pyrolysis products of the freons are now under study (80). Moreover, even unpyrolized fire-extinguishing agents are toxic at higher concentrations. A summary of these effects is available (101, 162).

Thermal degradation of plastics will yield monomers (89). Though this occurs generally at high temperatures, the percentage conversion in the case of polytetrafluoroethylene, polymethacrylate, and polymethylstyrene is high. Breakdown of plastics from large chain fragments may also include small molecules not particularly related to the structural unit; thus, methyl alcohol, hydrochloric acid, hydrofluoric acid and hydrogen cyanide may result from the vinyl halide and acrylonitrile polomers; carbonyl fluoride, from tetrafluoroethylene. The arcing of electrical equipment and ionizing radiation may produce photooxidation products of vapors in the atmosphere. Some of the more obvious reactions and products have been recorded (5, 41, 180).

The Bureau of Medicine and Surgery, U. S. Navy, has recommended interim threshold limits for 1-hour exposures to materials that may arise from malfunction of equipment as noted in Table 13-19a. It was emphasized that such limits represent the maximum allowable concentrations permissible under operational conditions and are not to be construed as permissible limits for repeated short-term exposures. It is envisioned that sufficient time between these peak exposures will have elapsed to allow complete recovery of the exposed individuals. In some cases, minor symptomatology may occur.

Table 13-19b gives the 60-minute provisional emergency limits for 5 substances for which no limits are available from the U. S. Navy submarine control program (136). In developing these limits, an attempt was made to follow the principles used by the NAS-NRC Committee on Toxicology

Table 13-19

Maximum Permissible Limits for Exposures Not Exceeding One Hour

a. U.S. Navy Limits

Ammonia	400 ppm
Monoethanolamine	100 ppm
Ozone	1 ppm
Oxides of nitrogen	10 ppm
Carbon dioxide	5%
Carbon monoxide	200 ppm
Hydrogen chloride	50 ppm
Hydrogen fluoride	5 ppm
Phosgene	1 ppm
Sulfur dioxide	10 ppm

(After U.S. Navy[212])

b. Provisional Emergency Limits for Space Cabin Contaminants Under Normoxic Conditions

Air Contaminant	Air Limit in Millimoles per 25 M^3 (ppm) for 60 min
2-Butanone	100
Carbonyl fluoride	25
Ethylene glycol	100
2-Methylbutanone	100
1,1,2-Trichloro, 1,2,2-Trifluoroethane and related congeners.	30,000

(After NAS-NRC[136])

in establishing emergency inhalation exposure limits for military and space chemicals (135, 212). Foremost among these principles as applied here is that the exposure not seriously interfere with the performance of a task or result in irreversible injury, although transient effects may be experienced. The emergency limits for these compounds contain no safety factor. They are considered to be tolerable for a single emergency during the duration of the mission. In addition to solvents (the butanones), carbonyl fluoride (COF_2) can provide an acute, short-term hazard from two material sources: pyrolytic decomposition of carboxy nitrosofluoride rubber at and above 450°F, and of polytetrafluoror ethylenes at and above 850°F. Accidental air contamination by ethylene glycol (CH_2OH_2) can arise from leaks in heat-exchange fluid systems or from its projected use as a space-suit coolant. Accidental contamination of the air with 1, 1, 2-trichloro, 1, 2, 2-trifluorethane and its pyrolytic products can occur from its use as a fire extinguisher. These two contaminants, trichloroethylene and 1, 1, 2-trichloro, 1, 2, 2-trifluoroethane pose special hazards in the event of subnormal operating temperatures of the catalytic burners. Dichloroacetylene (ClC = CCl) which is highly hazardous to health at extremely low levels, arises from the thermal degradation of trichloroethylene (174, 175). Similarly, products of high, but lesser toxicity arise from the pyrolysis of 1, 1, 2-trichloro, 1, 2, 2-trifluorethane, and related halogenated freon hydrocarbons (162).

Accidents in the launch and preparation areas as well as on board future spacecraft where extravehicular maneuvering units may be serviced may lead to exposure to rocket fuels and oxidizers. Some of the agents in Tables 13-15 to 13-18 fall into this group of compounds. Since accidental exposure to rocket fuels will probably lead to acute toxicity from relatively large doses of the compounds, data have been obtained for these modes of exposure. Definitive data are lacking for many of the following fuels, especially the interhalogen compounds: (7)

Hydrazine - N_2H_4

1 - 1 dimethylhydrazine - $(CH_3)_2N\text{-}NH_2$

Monomethylhydrazine - $CH_3NH\text{-}NH_2$

Pentaborane - B_5H_9

Decaborane - $B_{10}H_{14}$

Fluorine Containing Compounds:

OF_2	NF_3	TAMA
ClF_3	N_2F_4	TVOPA
ClF_5	NF_3O	NFPA
BrF_5	PFG	Compound R

Beryllium Containing Compounds:

Be
BeH_2

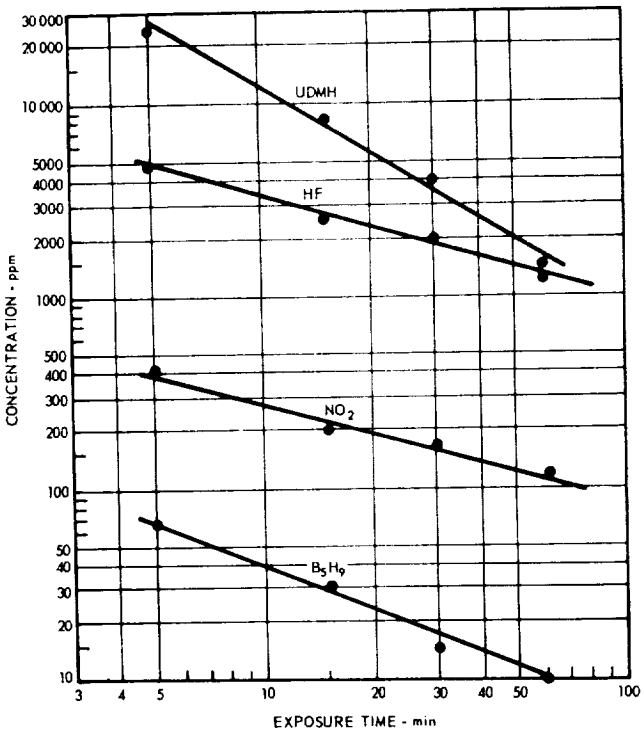
Figure 13-20a represents short-term toxic exposures to several of the more common compounds. These are data obtained on animals. They are presented to show the strong time-dependence of these agents. Table 13-20b shows the recommended TLV (8 hr) and provisional emergency tolerance limits for short times to rocket fuels and oxidizers with comparative data in animals showing wide range of species specificity of tolerance to these agents. Data are being obtained on the handling and toxicity of fluorine and other exotic propellants (7, 183, 227).

Carbon monoxide (CO), among all the spacecraft and launch pad contaminants presently known or envisaged for the immediate future, held a preeminent place of concern for the NAS-NRC Committee, primarily because it may well be the limiting toxicant. The following discussion is taken directly from the Committee Report (136). As covered above, carbon monoxide is contributed by materials, by some regenerative systems, and by man himself. CO from materials arise from the oxidative degradation of organics; in regenerative systems, CO is associated with the incomplete reduction of CO_2. In man, CO is produced from normal degradation of hemoglobin at a rate of about 0.4 ml/hr/man (188, 206). Because of its capacity to interfere with oxygen transport to the tissues and thus to affect cardiovascular and central nervous system function, CO has a broad capacity to synergize or potentiate biologic responses by altering host susceptibility.

The rate of CO uptake depends on its concentration and on the partial pressure of oxygen in the ambient atmosphere; its uptake is dependent on

Figure 13-20

Acute Toxicity of Propellants and Their Products



a. Toxicity of Fuels and Oxidizers in Rats

These data represent a compilation of animal studies covering comparative short-term inhalation toxicities of several fuels and oxidizers: unsymmetrical dimethyl hydrazine (UDMH); hydrofluoric acid (HF); nitrogen dioxide (NO_2); and pentaborane (B_5H_9). The data are presented to show the steep slopes of LC_{50} versus time. The very toxic nature of these compounds makes extrapolation to human LC_{50}'s most difficult.

(After Back and Pinkerton[8], adapted from Carson et al[28,29], Weeks et al[221], and Weir et al[222])

Figure 13-20 (continued)

b. Provisional Tolerance for Acute Exposure to Propellants and Toxic Products

Propellant	TLV (8 hr)	Emergency tolerance limits (No irreversible injury in humans)			No death in rats		No pathology in dogs	
		10 min	30 min	60 min	5 min	60 min	5 min	60 min
	ppm		ppm		ppm		ppm	
Unsymmetrical dimethyl hydrazine (UDMH)	0.5	100	50	30	19,800	813	600	50
Hydrazine (N_2H_4)	1.0	30	20	10	-	-	-	-
Pentaborane (B_5H_9)	0.005	-	-	-	62	7.5	-	-
Nitrogen tetroxide (N_2O_4)	5.0	30	20	10	190	72	104	28
Hydrofluoric acid (HF)	3.0	-	-	-	3,000	900	-	157
Ammonia	-	500	300	300				
Bromine pentafluoride* (BrF_5)	-	3	1.5	0.5				
Chlorine trifluoride (ClF_3)	-	7	3	1				
Chlorine pentafluoride* (ClF_3)	-	3	1.5	0.5				
Diborane (B_2H_6)	-	10	5	2				
Ethylene Oxide (C_2H_4O)	-	650	400	250				
Fluorine (Fl_2)	0.1	15	10	5				
Hydrochloric acid (HCl)	5.0	30	20	10				
JP-5 (in mg/L)* ±	-	5	5	2.5				
Monomethyl hydrazine (MMH)	0.2	10	7	3				
Nitrogen dioxide (NO_2)	5.0	30	20	10				
Nitrogen trifluoride (NF_3)	10.0	-	-	-				
Nitrogen trioxide (NO_3)	-	-	100	50				
Oxygen difluoride (OF_2)	0.05	0.5	0.2	0.1				
Perchloryl Fluorine (ClO_3F)	50	20	10					

* More data needed - very tentative levels

± Atmospheric maximum for total hydrocarbons from the fuel approximating saturated values is 5 mg/L.

(After Back[8], from the data of Carson et al[28, 29], Weeks et al[67], Weir et al[222, 225, 226]. Emergency tolerance limits are the recent recommendations of the NAS-NRC[134])

pulmonary diffusion. For men at work, the equilibrium concentration of carbon monoxide at levels up to 100 ppm reacting with hemoglobin in the blood is substantially complete in 6-8 hours. When the air contains 100 ppm of CO, the blood at equilibrium will contain 18-20% of carbon monoxide hemoglobin (HbCO); at 50 ppm of CO, 8-10% HbCO; at 25-30 ppm CO, 4-5% HbCO (25, 156, 192).

Recent investigations indicate that exposures to very low concentrations of CO can cause a subtle but significant decrement in high-level performance. Symptoms of headache, fatigue, and dizziness appear in healthy workers engaged in light labor when approximately 10% of the hemoglobin is HbCO (attained by breathing air containing 50 ppm of CO for 6-8 hours) (97, 115, 126, 146, 179, 217). The earliest detectable changes occur in the higher centers of the central nervous system. Cognitive and psychomotor abilities decrease at levels of 5% HbCO and the impairment increases with increasing concentration of CO in the blood stream (184). There was a suggestion that levels below 5% HbCO also affected function, but this was not established in the study. Reduction of the threshold of light sensitivity of the eye at 5% HbCO is equivalent in magnitude to that caused by an altitude of 8,000 - 10,000 feet above sea level (77, 123, 184). (See Table 2-57.) These reports of effects at such low levels of HbCO are of particular concern, not so much from the standpoint of their being a serious threat to health, but because they might compromise the high level of judgment and performance that is required of the pilots and other occupants of space vehicles. Subjects may accommodate to the effects of inhaled CO. When men were exposed continuously in a submarine at 50 ppm CO they complained of headache, but a 60-day exposure of 40 ppm was without observed effect (54).

Carbon monoxide has been shown to be synergistic with the toxic action of several other atmospheric contaminants (217). However, those experimental tests were conducted at relatively high concentrations of acute exposure, and there is no information available concerning the threshold concentrations at which significant toxicologic interactions of CO with other contaminants might occur. It is reasonable to assume, however, that during space flight, conditions which would increase an individual's sensitivity to CO might occur (e.g., decreased cardiac output, severe exercise hypoxemia). Further studies are needed to evaluate these factors.

In view of the decrement of CNS and visual function that have recently been reported at HbCO levels of 5% or less, and because there is inadequate information concerning the threshold concentration at which CO might decrease the physiological reserve, the Committee felt that the concentration of CO should be kept as low as possible. Consistent with this philosophy, therefore, the Committee recommended a provisional limit of 15 millimoles/25 m^3 (15 ppm) for both 90 and 1000-day missions. At this concentration it is probable that the HbCO level at equilibrium would not exceed 2% or 3%, only slightly greater than the normal level in individuals with no environmental exposure to CO (6).

Figure 13-21 represents the effects of acute exposure to carbon monoxide used to set military limits. Specific effects of carbon monoxide on vision are covered in Light Environment, (No. 2).

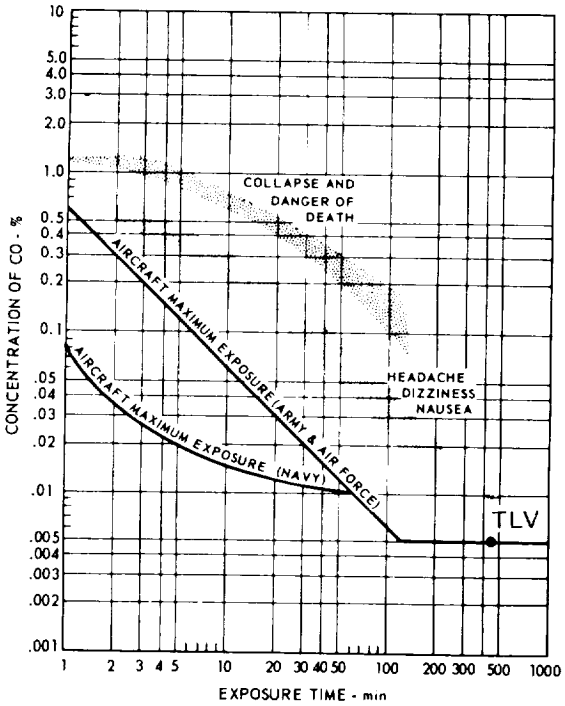


Figure 13-21

Carbon Monoxide

This graph shows the effects of carbon monoxide on man as functions of concentration and exposure time. Milder effects are shown as a lightly shaded band of exposure times and concentrations, while dangerous or lethal times and concentrations are grouped in the heavily shaded band. The solid lines are the exposure limits set by the military services for aircraft. The point marked at 0.05% CO (50 ppm) and 480 minutes is the current Threshold Limit Value (TLV) for 8-hours-a-day exposure in industry.

(After Back and Pinkerton[8], adapted from Department of Defense[46], Haldane[76], Henderson and Haggard[85], and Sayers et al[178])

Sampling and Analysis of Toxic Contaminants

In view of the numerous compounds at low concentrations, sampling and analyses for toxic contaminants in spacecraft is a difficult problem. Sampling techniques are being improved (21, 49, 155, 207). Analytic techniques are numerous but often give variant results for the same atmosphere (36, 45, 129 130, 155, 182). Gas-chromatographic techniques have been the most commonly used. Current studies of infrared spectroscopy interferometry (19, 53, 182). double-resonance microwave spectroscopy (197, 216), mass spectrometry (166, 207), and other new techniques (49, 66) offer some promise for ground-based and possibly inflight sampling and analysis. Sampling of water supplies for organic atmospheric contaminants (190) and inorganic contaminants (137, 191) in space cabins is covered in Water, (No. 15).

PARTICULATES AND AEROSOLS

Many of the toxic materials covered above may be in particulate or aerosol form. Even nontoxic particulates may be a hazard in space operations because of the zero gravity environment (22). In reviewing toxic hazards, one must be concerned with the fact that aerosols can act as condensing nuclei for toxic gases (180, 214). This facilitates the entrance into the lower respiratory tract of such materials which, because of their high water solubility, are generally trapped in the upper respiratory tract. It also provides for local areas of extreme irritation due to the concentration of the toxic gas in a finite area.

The aerosols may be classified as shown in Table 13-22. Generally, aerosols have a diameter of less than 50μ. The usual range is from 0.01μ

Table 13-22

Classification of Aerosols

Smokes:	Usually solid particles of carbon resulting from the burning of carbonaceous material. Carbon smoke is composed of particles about 0.01μ which tend to coagulate or agglomerate rapidly into long, irregular filaments several microns in length.
Dusts:	Solid particles ranging in size from 0.1μ or less, which produce a haze, to large particles found in a sandstorm which are likely to be the size range considered to be aerosols.
Fogs:	Liquid droplets generated by atomization or condensation of volatile substances on minute nuclei. The size of these particles is often quite large, ranging from 4 to 40μ, as in a natural water fog.
Fumes:	Solid particles generally produced by sublimation, combustion, or condensation, usually between 0.05 and 0.5μ. Fumes are produced by arcing at high temperature.

(After Punte[148])

to 10μ. Surface air on the Earth contains a considerable aerosol load. The problem, unique in the closed living space, is the tendency of these to increase in numbers and mean diameters. In submerged nuclear powered submarines the concentration reached a steady state concentration of about 0.4μg/L at approximately 100 hours (102). This compared unfavorably with the aerosol concentration in Los Angeles on a smoggy day where the concentration averaged 0.2μg/L. Also there was approximately 8 times the content of organic aerosols in the submarine.

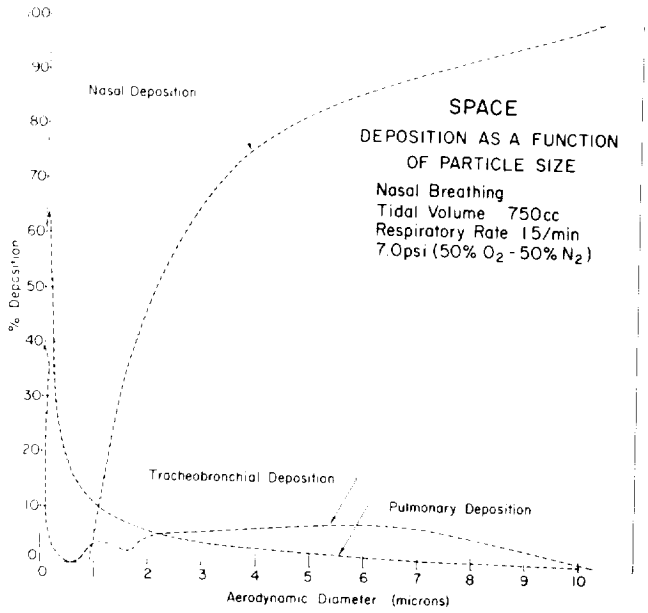
Factors influencing the stability of aerosols may be altered in the space vehicle, but the exact nature of atmospheric, electrostatic, and other effects are not clear. Under 1 g conditions on Earth, total retention of particles in diameter size 0.2μ to 5μ varies between 20 and 90%. Of the particles gaining entrance to the lower respiratory tree, the maximum particle load at that site is at the 1 μ diameter level. The size which is least retained is 0.4μ. The disposition of deposited particles depends on their solubility. Those which reach the lower respiratory tract and are water soluble are rapidly absorbed into the blood stream and a toxicologic effect may occur in a short term. Less soluble substances and those deposited on the airway are moved by the flow of mucous and ciliary movement to the pharynx, where they are swallowed and excreted from the gut.

The lack of gravity will probably have an effect on the site of deposition of aerosols (22, 133). Figure 13-23a represents calculation for respiratory deposition sites for particles of different aerodynamic diameter in space cabins at zero g. Figure 13-23b shows similar calculations for the Earth environment. Figure 13-23c compares total deposition in orbiting spacecraft vs. Earth environment. Substitution of helium or another gas for nitrogen would, in this pressure range, alter viscosity by only a few percent, and hence should not alter these "deposition curves" significantly. The deposition

Figure 12-23

Comparison of Theoretical Deposition of Aerosols in Space Cabin Atmospheres at Zero Gravity and in Air at Earth Gravity as a Function of Particle or Droplet Size

(After Busby and Mercer [23])



a. In the Space Cabins Atmospheres in a Weightless Environment

b. In Air at One Atmosphere in a 1G Environment

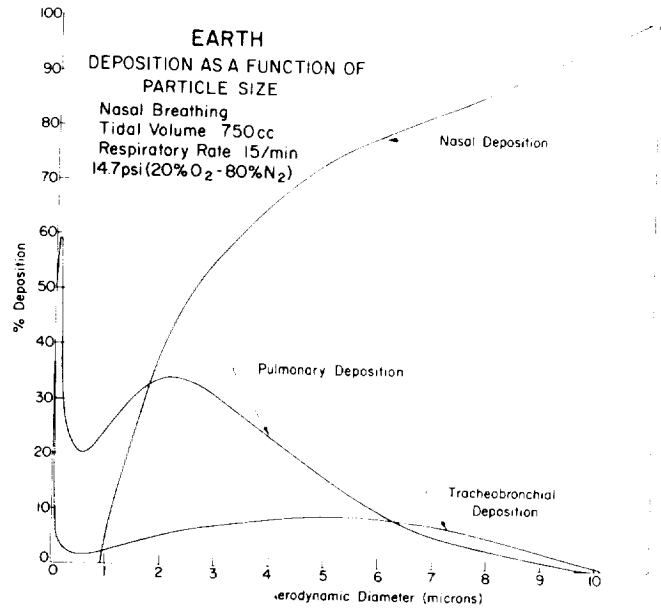
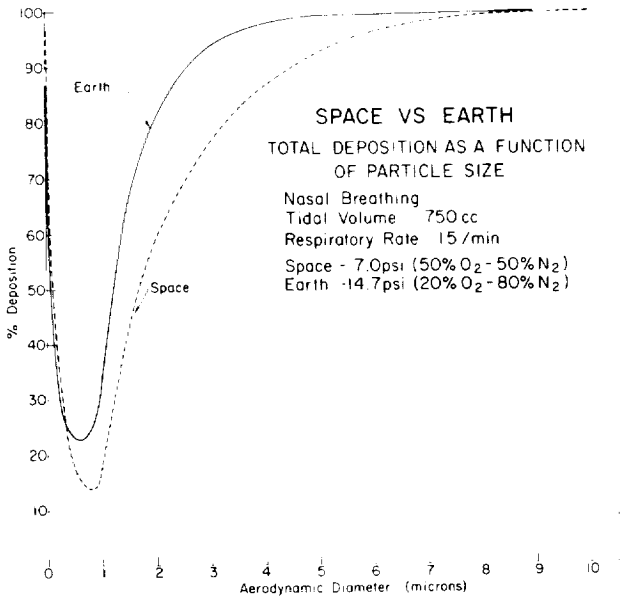


Figure 12-23 (continued)



c. Comparison of Total Deposition as a Function of Particle or Droplet Size in the Earth (Unit Gravity) and Space (Weightless) Environment

rates have been adjusted for differences in pressure between the cabin and the Earth. There are no definitive empirical data to support these theoretical curves.

Theoretical considerations of the role of zero gravity in generation of aerosols imply that the amount of particle or droplet contaminant inhaled in orbit could be increased over the amount inhaled in a similar situation under one-gravity environment (22, 23). The predicted characteristics of particle and droplet deposition in the respiratory passages for the weightless environment show that in space, as on Earth, the nose or mouth should continue to operate as highly efficient filters, protecting the lower respiratory passages from all particles and droplets above about 10 microns in diameter. Fortunately, this size is considerably less than that of particles and droplets of most contaminants which may be introduced into the spacecraft cabin atmosphere. In this respect, it should be pointed out that the use of powdered chemicals of particle sizes greater than 10 microns in space would be an important safety measure.

It is possible for an astronaut to be exposed to aerosols and droplets (e.g., liquid ejected as a fine spray) less than about 10 microns in diameter. The "deposition curves" predict that fewer inhaled particles and droplets between about 0.5 and about 10 microns in diameter will be deposited in the lower respiratory passages, especially in the pulmonary region, (Figure 12-23a vs. 12-23b) in the weightless as compared to the one-gravity environment. This implies that weightlessness might offer some protection to an astronaut from certain contaminants which, if inhaled in a similar concentration in a unit gravity environment, would be irritating to or damage alveoli

and respiratory bronchioles, or produce systemic toxic effects by being absorbed. It is of interest to note that weightlessness exerts its greatest protective effect in the pulmonary or non-ciliated region of the respiratory passages -- a region where deposited contaminants are not moved out of the respiratory passages by ciliary action. The zero-gravity deposition patterns imply that the concentration of particles and droplets one micron in diameter inhaled into the respiratory passages in the weightless environment could be approximately doubled before the percent deposition of such contaminants in the pulmonary region in this environment would be equivalent to their percent deposition in the unit gravity environment. Similarly, the inhaled concentration of particles and droplets could be increased by approximately 6 times for particles and droplets 2 microns in diameter, 7 times for those 3, 4, and 5 microns in diameter, 6 times for those 6 microns in diameter, 5 times for those 7 and 8 microns in diameter, and 3 times for those 9 microns in diameter. However, even though it is predicted that the pulmonary deposition of inhaled particles and droplets between about 0.5 and about 10 microns in diameter will be significantly reduced in the weightless environment, one must remember that such contaminating particles or droplets could still be suspended in a concentration which would be harmful.

Since the weightless space-cabin environment does not alter the high percent deposition of particles and droplets below about 0.5 microns in diameter in the lower respiratory passages, the consequences of inhaling such contaminants will probably not be different as compared to the one-gravity sea-level air environment. Contaminants of this size are most likely to be in the form of fumes or smoke. Since particles or droplets below 0.9 microns in diameter will apparently not be deposited in the nasal (or oral) regions of the respiratory passages, their inhalation should not produce clinical problems in the upper respiratory passages. On the other hand, because of the very high percent deposition of particles and droplets below about 0.5 microns in diameter, tracheobronchial and pulmonary tissues could be selectively irritated by particles of this size.

Whether or not particles or droplets larger than a few hundred microns in diameter (e.g., several hundred microns to 1 cm) can be inhaled will depend less on particle and droplet size, and more and more on such important factors as particle or droplet shape and density, their spatial relationship to the inspiratory air stream and mouth and nasal openings, their velocities and directions of movement relative to an astronaut, the velocity-time profiles of the inspiratory and expiratory air streams, and the duration of the pause between inspiration and expiration (22). Taking all of these factors into consideration, it is predicted that various particles, especially those of low density, and droplets of possibly up to 1 cm in diameter, could very well be inhaled in the weightless environment. Accordingly, it is thought that as compared to on Earth, an astronaut in space might run a somewhat higher risk not only of inhaling large particles and droplets into his nose and mouth, but also of aspirating large particles and droplets of up to 1 cm in diameter into his lower respiratory tract. The medical significance and treatment of emergencies to the respiratory tract, skin and eye from particulates in space cabins has been recently reviewed (22).

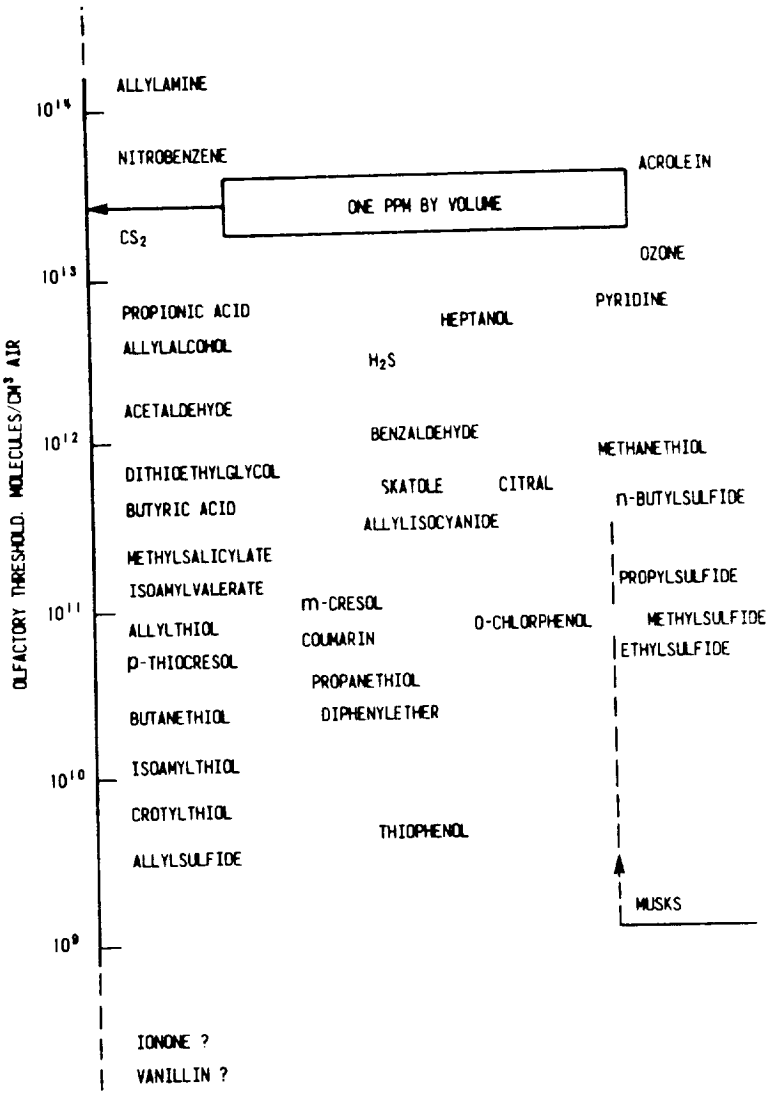


Figure 13-24

Olfactory Thresholds

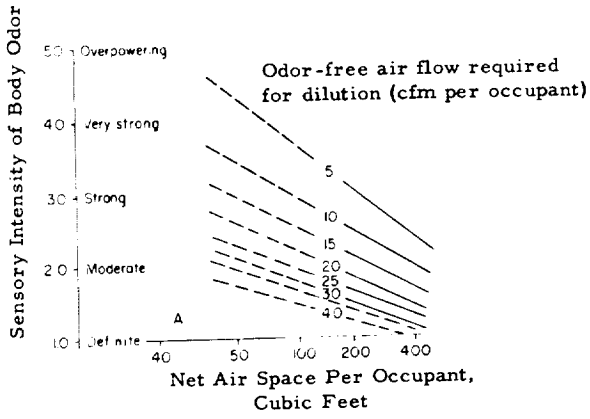
(After Dravnieks[48])

Figure 13-25

Ventilation Requirements in Relation to Net Air Space and Body Odor

The graph shows that the intensity of body odors in a given area depend on the rate of flow of odor-free air. The solid portions of the curves are based on experimental data; the broken parts are extrapolations to the conditions found on aircraft.

(After Yaglou et al [232])



Ionized aerosols have often been discussed as a cause of behavioral changes during various meteorological phenomena (105, 106) and with certain air conditioning devices (9). Other biological effects such as on tracheal cilia and lower biological forms have also been reported. The concentration of aerosol ions in the natural or submarine atmospheres has always been low. In nuclear submarines, sparking electrical equipment and radium dials were probably responsible for ion concentrations of less than $1000/cm^3$ averaging about 450 (+) ions and 250 (-) ions/cm^3 (102). No data have been obtained in operating space cabins. In view of the low concentration of aerosol ions in submarines , the uncertain significance of the experiments with isolated tracheal preparations, and equivocal results of studies with human behavior (9, 105, 106, 140) the potential significance of these aerosols in space cabins is not clear. Presence of ozone in the outflow of generators using high voltage gradients to direct ions generated by radioactive isotopes or using spark discharges to generate ions is a problem which must be eliminated in future experiments.

Odors in Space Cabins

The human olfactory sense permits detection of vapors of many organic substances at concentrations of 10^{11} to 10^{13} molecules/cm^3 of air and some at concentrations as low as 2×10^9 molecules/cm^3 (48, 61). Table 13-24 represents several known odor thresholds. Indications also exist that substances at one-tenth of the threshold may influence the odor quality of other odorants present at concentrations well above the threshold (99).

Fortunately, the human olfactory sense adapts to odors quite rapidly (70). Experience in space cabins and space cabin simulators suggests that crews are not bothered by odors in the cabin which may overwhelm new additions to the crew. Data are available on odor control and the atmosphere exchanges required for elimination of body odor in a densely populated space (143, 232). This is shown in Figure 13-25. A thorough review has been made on the use of the olfactory sense in detecting and diagnosing malfunctions in equipment systems (70).

MICROBIAL CONTAMINANTS

The microbial flora of the space cabin represent particulate contaminants which can have significant effects on crew and equipment. The human, is of course, the major source of microbes in the space cabin. The normal bacterial flora onthe skin, mucous membranes and intestines of man have received a recent thorough review (153). Special emphasis is given to the differences in flora of various body sites. The control of the waste management system depends on the knowledge of the microbial environment. The clogging of filter beds after prolonged exposure may be an engineering problem. Alkali superoxide beds receive bacteria from the gas stream, but the effect is mostly physical rather than chemical (20). Especially in tropical climates, microbes can cause deterioration of electronic components.

Microbial contamination of drinking water is a major problem covered in Water, (No. 15). In case of unavoidable contamination of water supplied by bacteria, organic halogen compounds may be used for sterilization (75, 127). However, optimum concentrations of the agents and modes of dispensing depend on the level of reducing agents present along with the bacteria and thus require empirical study for spacecraft application. Heat appears to be the best solution to date (137, 191).

Space cabins with their limited space and hygienic facilities tend to increase the problem of bacterial control. Studies performed in sealed cabins suggest that there is an increase in the total skin flora especially in axillary, groin, and other fold areas (18, 63, 64, 68, 84, 117). This tendency is increased by the wearing of a space suit and by high humidity (64). The buildup tends to reach a plateau after variable periods of time in a given environmental situation. There is an exchange of fecal and dermal flora between enclosed subjects with no tendency for pathogens to become predominant. Throat flora are exchanged less rapidly (84).

Increase of atmospheric P_{O_2} to 5 psia 100% oxygen tends to produce a variable increase in the percent of skin aerobes (84, 153). Fecal flora retain a predominant percentage of anaerobes which continue to contaminate the skin. Buildup of organisms on the wall and furniture of the chambers is predominantly staphlococci, Gram negative rods and streptococci in both high and normal oxygen environments (18, 64). Within space suits in 100% oxygen with minimum hygienic procedure,the bacterial count of the body reaches a maximum in about one week and remains elevated or declines thereafter. Wearing of suits does not seem to alter the components of the flora (64).

The major sources of bacterial contamination in a space cabin are from fecal material and skin. Much dry weight of the stool is bacteria. Alteration of the normal bacterial flora by different space-food diets has been covered in Nutrition, (No. 14). Basic data may be found in References (26, 38, 58, 96, 117, 121, 132, 152, 154, 189). Fecal flora tend to retain their person-to-person individuality much more than do those of the skin. An occasional black slime-and-gas-forming prophalytic anaerobe is found (62, 63). In actual space flight, there appears to be an increase in the number of bacteria in the craft and on the astronauts' skin and mucous membranes (229).

Little is known about the viral population in sealed systems (229). Subtle interactions between the gaseous environment and host may alter viral infectivity (69).

To date, there has been no tendency for an increase in pathogens or a decrease in body resistance to pathogens in chamber studies under minimal hygienic conditions (117, 118, 119, 120). Pathogens have been transferred from subject to subject with no outbreak of infection (63). Presence of 100% oxygen at 5 psia does not appear to alter grossly the susceptibility of animals to infections by pathogens (229). The isolated spacecraft environment would be expected to eliminate exogenous disease. Radiation and subacute stress may alter response to infection in some future missions but no problems have arisen to date. In nuclear submarines with large crews, there tends to be a

flurry of infectious disease of primarily respiratory type in the first few weeks of a cruise but this incidence drops rapidly as "herd immunity" is developed (229). This pattern may be expected in large space crews of the future.

An interesting finding in recent studies was death in several animals following administration of tetracycline drugs when in a 100% oxygen 5 psia atmosphere (202). It is only presumed that tetracycline was the prime factor, but the finding of a possible altered toxicity to a drug in this atmosphere requires further study.

The problems of sterilizing spacecraft components for avoiding microbial contamination of other planets and to avoid back-contamination of Earth are now under study (10, 16, 39, 55, 59, 91, 95, 98, 108, 109, 110, 111 112, 113, 114, 124, 128, 143, 171, 181, 233). Data are also available on the leakage of bacteria from pressurized space suits (211).

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